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Assessment of Intra- and Inter-Individual Metabolic Variation in Special Operations Forces (SOF) Soldiers

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Gabaree, C.L.V., Jones, T.E., Murphy, T.C., Brooks, E., Tulley, R.T., Askew, E.W.

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The purpose of this study was to quantify both within- and between-subject variation in respiratory and hormonal responses during repeated bouts of prolonged, treadmill exercise and recovery as the basis for individualization of operational rations. Eighteen U.S. Army Special Operations Forces (SOF) soldiers participated as test subjects. Diet, hydration status, energy expenditure, and ambient conditions were controlled. Extremely low variation between individuals in respiratory variables and biochemical variables indicated insignificant variation between individuals in substrate utilization during exercise. Also, a dietary carbohydrate intake of 4.4 g CHO · kg BW^{-1} was insufficient to prevent a transition from a carbohydrate- to a fat-predominant metabolism. Despite consuming nearly twice the RDA for protein, more than half of these well-trained men were in negative nitrogen balance for 6 days of the 11-day study. This evidence supports the contention that protein requirement may increase with increasing physical activity. Additionally, relative contributions of fat and carbohydrate in the diet may also induce differences in nitrogen requirements. Also, ingestion of a carbohydrate supplement improved exercise performance. Finally, optimal nutritional support during mission deployment may be made on the basis of body weight, predicted energy expenditure, exercise intensity, and environmental concerns.

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ASSESSMENT OF INTRA- AND INTER-INDIVIDUAL METABOLIC VARIATION IN SPECIAL OPERATIONS FORCES (SOF) SOLDIERS

Catherine L.V. Gabarée, Ph.D.[1]
Tanya E. Jones, M.S., R.D.[1]
LTC T. Clifton Murphy, Ph.D.[1]
Ellen Brooks, R.N., M.N.[2]
Richard T. Tulley, Ph.D., DABCC[3]
COL Eldon W. Askew, Ph.D.[1]

[1]Military Nutrition Division, U.S. Army Research Institute of Environmental Medicine
Natick, MA 01760

[2]Clinical Unit,[3]Clinical Research Laboratory, Pennington Biomedical Research Center,
Louisiana State University Baton Rouge, LA 70808

DISCLAIMER

The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the U. S. Army or the Department of Defense.

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on the use of volunteers in research.

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LISTS OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

USARIEM	U.S. Army Research Institute of Environmental Medicine
USAMRDAL	U.S. Army Medical Research, Development, Acquisition and Logistics Command
USANRDEC	U.S. Army Natick Research Engineering & Development Center
PBRC	Pennington Biomedical Research Center
REE	resting energy expenditure
DEXA	dual energy X-ray absorptiometry
BW	body weight
$\dot{V}O_2$	oxygen consumption per minute
$\dot{V}CO_2$	carbon dioxide production per minute
$\dot{V}O_2max$	maximal aerobic power
HR	heart rate
R-Day	rest day
E-Day	experimental exercise protocol day
R-Value	respiratory gas exchange ($\dot{V}CO_2/\dot{V}O_2$)
CHO	carbohydrate
PRO	protein
REP-1	1st replicate exercise trial (morning of day 4)
REP-2	2nd replicate exercise trial (morning of day 7)
REP-3	3rd replicate exercise trial (morning of day 10)
CHO-0	carbohydrate treatment: artificially sweetened placebo
CHO-1	carbohydrate treatment: 2.2 g CHO · kg body weight^{-1} administered immediately post REP-trial and placebo at 20, 40, and 60 minutes of exercise during the afternoon (CHO-1) trial.
CHO-2	carbohydrate treatment: 1.0 g CHO · kg body weight^{-1} administered immediately post REP-trial plus 0.4 g CHO · kg body weight^{-1} at 20, 40, and 60 minutes of exercise during the afternoon (CHO-2) trial.
$\bar{X}$	mean
SD	standard deviation
CV	coefficient of variation (SD/$\bar{X}$ · 100%)

EXECUTIVE SUMMARY

The purpose of this study was to quantify both within- and between-subject variation in respiratory and hormonal responses during repeated bouts of prolonged, treadmill exercise and recovery. Additionally, the effect of a liquid carbohydrate supplement on endurance time-to-exhaustion was examined.

Eighteen U.S. Army Special Operations Forces (SOF) soldiers (age, 29±4 y; height, 178±9 cm; body weight (BW), 83.6±8.3 kg; percent body fat, 18.4±4.7 %; $\dot{V}O_2$max, 4.3±0.4 L· min^{-1}) lived on an in-patient metabolic ward for 11 consecutive days. Diet, hydration status, energy expenditure, and ambient conditions were controlled. Volunteers were fed a weight-maintaining, controlled diet which simulated the amount of carbohydrate and protein consumed during field training (4 g CHO · kg BW^{-1} and 1.5 g PRO · kg BW^{-1}). Pre-experimental height, body weight, body composition, and maximal aerobic power were determined on days 1 and 11. Two standardized rest days (R) (days 2,3,5,6,8 and 9) preceded each exercise day (E) (days 4,7, and 10). Total urine and feces were collected daily, and sweat was collected during each exercise trial. Nitrogen (N) balance was estimated daily from N intake, and nitrogen output in urine, feces, sweat and blood. Fasting respiratory gas exchange was measured on all days except the exercise days. Rest days consisted of two 60-min submaximal exercise sessions (each session consisted of 30 min cycling and 30 min treadmill walking). Test days (E) consisted of two prolonged (approximately 2 hours) treadmill exercise sessions separated by a six-hour rest and feeding period. Exercise intensity and duration for the morning sessions (REP-1, REP-2, and REP-3) were as follows: 35% of the previously determined $\dot{V}O_2$max for 5 min, 50% $\dot{V}O_2$max for 55 min, and 75% $\dot{V}O_2$max for 60 min. After the 6-hour rest and feeding period, volunteers completed an afternoon exercise trial (CHO-0, CHO-1, and CHO-2) which proceeded as follows: 35% $\dot{V}O_2$ max for 5 min, 50% $\dot{V}O_2$max for 55 min, 75% $\dot{V}O_2$max for 30 min, 80% $\dot{V}O_2$max for 30 min, and 85% $\dot{V}O_2$max until volitional exhaustion. During the three afternoon exercise sessions volunteers were assigned to a placebo (CHO-0) and two carbohydrate beverage trials (CHO-1, CHO-2) administered in a counterbalanced, single-blind design. The quantity and timing of the glucose-polymer solutions were as follows: CHO-0 = artificially sweetened placebo; CHO-1 = 2.2 g CHO · kg BW^{-1} administered immediately post REP-trial; and CHO-2 = 1.0 g CHO · kg BW^{-1}

administered immediately post REP-trial plus 0.4 g CHO · kg BW^{-1} given three times at 20-minute intervals during CHO-2 trial. Respiratory gas exchange was measured for 5 minutes at 20, 50, 75, 100 and 120 min of exercise. Venous blood samples obtained before (PRE), during (40 and 70 min), and immediately after exercise (IP, 10R) were analyzed for glucose, triglyceride, lactic acid, β-hydroxybutyric acid, glycerol, free fatty acids, insulin, cortisol, adrenocorticotropic hormone (ACTH), catecholamines.

Results show that fasting RQ values decreased significantly from 0.87 ± 0.05 on day 1 to 0.82 ± 0.04 on day 2, and then remained at approximately 0.79 through day 11. Variation in resting R-value between individuals from Day 1 to Day 11 was very low and ranged from 3.9% to 5.7%. During the morning exercise trials, there were no significant differences found within or between individuals in RQ at any work intensity (% $\dot{V}O_2$ max). However there was a stepwise decrease at each exercise intensity from day 1 to day 10. Further, the coefficients of variation (CV) for RQ in the same individual and between individuals were very low (CV) ranging from 2.3-2.5% and 2.5-4.9%, respectively) indicating insignificant variation between individuals in substrate utilization during exercise. As expected, RQ was significantly higher in the CHO-1 and CHO-2 trials and variation between individuals in RQ during the afternoon exercise trials also remained very low (CV ranged from 1.1-5.7%). That the variation remained low despite an increase in RQ indicates all the volunteers utilized the additional CHO made available to them. During the morning exercise trials there were no significant differences in blood chemistries within or between individuals at any exercise intensity. Run-to-exhaustion times were significantly higher for CHO-1 (6%) and CHO-2 (17%). Additionally, CHO-2 was significantly greater than CHO-1.

These results suggest that in this group of soldiers doing prolonged endurance exercise (approximately 4,000 kcal · d^{-1}) that variation between volunteers in R-value at rest (3.9-5.7%) and during exercise (2.5-4.9%) was extremely low. This extremely small variation between individuals is a clear indication that despite differences in pre-experimental diet, training, and body composition among this group of SOF operators, metabolic differences, per se, were negligible. Also, under the conditions of this study a dietary carbohydrate intake of 4.4 g CHO · kg BW^{-1} was insufficient to prevent a transition from a carbohydrate- to a fat-predominant metabolism. Despite consuming 1.5 g PRO ·kg BW · da^{-1}, an amount nearly twice the protein RDA of 0.8 g · kgBW $^{-1}$

· da^{-1} (Recommended Dietary Allowances (RDA) ninth revised edition, 1980), more than half of these well-trained men were in negative nitrogen balance for 6 days of the 11-day study. This evidence supports the contention that protein requirement may increase with increasing physical activity. Additionally, relative contributions of fat and carbohydrate in the diet may also induce differences in nitrogen requirements, particularly during periods of increased physical activity. Also, ingestion of a carbohydrate supplement containing 183±19 g CHO improved exercise performance. Finally, optimal nutritional support during mission deployment may be made on the basis of body weight, predicted energy expenditure, exercise intensity, and environmental concerns.

INTRODUCTION

The physically active SOF soldier requires an operational ration that can be optimized for weight, volume, acceptability and nutrition. Existing ration systems can not be reconfigured to meet these SOF-specific ration requirements. Currently, the SOF soldier is self-selecting foods from military and commercial sources for each mission. Unfortunately, these self-selected foods do not meet mission-critical nutrient requirements. The Sustainability and Science and Technology Directorates of Natick RD&E Center assisted by the U.S. Army Research Institute of Environmental Medicine (USARIEM) were requested in 1991 by the U.S. Army John F. Kennedy Special Warfare Center and School (JFKSWCS), Ft Bragg, NC to develop a computer program that will allow the tailoring of food and beverage components to optimally support the physical and mental capabilities of the SOF soldier in the field based on his individual and/or mission-specific requirements. In 1992 the U.S. Special Operations Command (USSOCOM) approved the SOF Individual Operational Ration Technology Base project and funded it for three years (FY92-94).

Starting in 3Q92, USARIEM surveyed SOF soldiers to obtain preliminary information on physical activity and nutrition practices. Additionally, physical characteristics which impact on physical performance (age, height, weight, surface area, percent body fat, lean body mass, aerobic exercise power) of SOF soldiers presented in the scientific and technical literature were summarized. This information revealed that SOF soldiers are a statistically distinct sub-group within the U.S. Army based on physical characteristics which affect physical performance (Gabarée et al., 1994).

A key issue in ration customization is the question of metabolic variability among individual SOF soldiers. During FY93 USARIEM conducted the study reported herein specifically to determine the inter-individual variation in substrate utilization among SOF soldiers at rest and during exercise. These data could be incorporated into a user-friendly computer software program, Ration Expert Advisor Program (REAP), that could assist the individual SOF soldier or "A" Detachment in customizing lightweight, nutritionally optimized rations from military and/or commercial products. REAP will predict both individual and mission-specific nutrient requirements, analyze the nutrient

composition of self-selected foods, and then suggest alternative choices that optimize the match between predicted and selected nutrient needs.

RESEARCH OBJECTIVES

This study evaluated both intra- and inter-individual metabolic variation during repeated bouts (3 trials) of prolonged (approximately 2 hours), treadmill exercise and recovery. The underlying hypothesis was that significant variation between individuals, exceeding intra-individual variation, would indicate different nutritional requirements for optimization of physical performance during mission deployment. Variation due to exercise, diet, and time-of-day was strictly controlled. Measurement of respiratory gases during rest and steady state exercise provided an indication of whole-body substrate oxidation. Measurement of blood metabolites and hormones during exercise and recovery provided data for evaluation of variation in the internal environment.

Additionally, this study examined the effect of a carbohydrate supplement and the timing of the carbohydrate supplement administration on metabolic response to exercise and recovery and on endurance time-to-exhaustion. The first hypothesis was that carbohydrate supplement administration would enable a greater reliance on carbohydrate metabolism during treadmill exercise at high intensities and increase time-to-exhaustion. Secondly, it was hypothesized that the timing of the carbohydrate supplement administration i.e., before or during exercise, would effect carbohydrate metabolism during exercise and run-to-exhaustion times.

METHODS

STUDY VOLUNTEERS

Eighteen healthy Special Operations Forces (SOF) soldiers volunteered for participation in this study. Before initiation of the study, each volunteer was given a medical examination and was medically cleared for participation. Volunteers over the age of 35 years underwent a diagnostic graded exercise test in addition to the general medical examination. All attendant risks and benefits of participation were fully explained and each volunteer completed and signed a Volunteer Agreement Affidavit which had been previously approved by the USARIEM Human Use Review Committee, the Human Use Review Office at USAMRDAL, and the Louisiana State University (LSU) Institutional Review Board.

Of the eighteen SOF soldiers, nine soldiers were members of the 7th SFG(A), Fort Bragg, NC and nine were members of the 10th SFG(A), Fort Devens, MA. Ten were members of airborne High Altitude Low Opening (HALO) teams, 5 were members of a Self-Contained Underwater Breathing Apparatus (SCUBA) team and 3 were Military Intelligence (MI) team members. Two of the MI soldiers were not yet SOF qualified. There were no smokers in this group of volunteers, however, one volunteer, #12, occasionally used smokeless tobacco. Physical characteristics of the volunteers are summarized in Table 1 and individual data are presented in Appendix A. Subject #17 was unable to complete all three exercise trials due to aggravation of a prior injury. His physical characteristics are included in the individual data in Appendix A but are not included in the summary data in Table 1 nor are his experimental data included in the analyses presented in this technical report.

Random selection of SOF soldiers as volunteers for participation in prolonged studies is precluded by functional dependence on the team as the operational unit. In order to disable as few teams as possible, volunteers were recruited from available A teams. In order to delimit the constraints imposed on generalizability by the lack of random sampling, physical variables which directly impact on physical performance were compared to a summary of mean values for SOF soldiers obtained from a search of the Technical and scientific literature and previously reported (Gabarée, 1994). The

SOF soldier-volunteers participating in this study were similar to the larger group in each comparison: age, height, weight, percent body fat, lean body weight, DuBois surface area (DuBois, 1916), and maximal aerobic power ($\dot{V}O_2max$) (Table 1). It is reasonable to conclude, then, that although the volunteers for this study were not randomly selected, they were a representative sample.

Table 1. Physical characteristics of the SOF soldier-volunteers participating in this study and SOF soldiers who had participated in previously reported studies.

	Study Volunteers n=17	SOF Soldiers ‡ n=48
Age (years)	30±3	29.0±1.8
Height (cm)	178.3±8.1	180.2±0.6
Weight (kg)	83.2±8.7	81.5±1.9
Body fat (%)	18.6±5.8	16.6±1.3
LBW (kg)	67.6±5.8	67.7±1.7
Surface Area (m^2)	2.02±0.14	2.01±0.02
$\dot{V}O_2max$ ($L \cdot min^{-1}$)	4.31±0.4	4.30±0.3
$\dot{V}O_2max$ ($mL \cdot kg\ BW^{-1} \cdot min^{-1}$)	52.2±5.2	53.3±4.8
$\dot{V}O_2max$($mL \cdot kg\ LBW^{-1} \cdot min^{-1}$)	63.78±4.8	63.5±5.4

‡ Gabarée, 1994

EXPERIMENTAL DESIGN

This study was conducted at the Pennington Biomedical Research Center (PBRC), Baton Rouge, LA. Data were collected in two iterations separated by a 14-day recess. The first iteration was conducted during the month of June and the second iteration was conducted during July. The first group of volunteers was garrisoned at Fort Bragg, North Carolina and the second group was garrisoned at Fort Devens, Massachusetts. Since both teams were accustomed to performing vigorous, physical activity in ambient conditions, and, since ambient conditions in North Carolina in June and Massachusetts in July are hot and humid, it is reasonable to assume that all the volunteers were fully acclimatized to the heat upon their arrival at PBRC.

Each volunteer participated for an eleven-day period. During that time he resided on the metabolic ward at PBRC. In addition to strict dietary control, the volunteers' participation in physical exercise was controlled and supervised. Hydration status was closely monitored and ambient conditions were controlled. In order to minimize variation in physiological measurements due to perturbations in circadian rhythmicity, measurements on each individual were taken at the same time of day and "lights out" was at the same time each evening. Figure 1 presents the 11-day experimental period diagrammatically. A schematic for the entire study is presented in Appendix B.

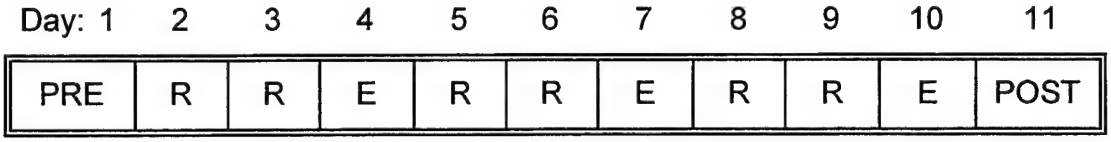

Figure 1. Diagrammatic representation of the 11-day experimental period, where PRE= day 1, R=rest day, E=experimental exercise protocol day, and POST=day 11.

On Day 1 (PRE), the volunteers began the experimental diet (see EXPERIMENTAL DIET) and preliminary measurements were taken. Preliminary

measurements included: resting energy expenditure (REE), height, weight, percent body fat, muscle fatiguability for estimation of muscle fiber composition, anthropometric measurements for determination of somatotype, and $\dot{V}O_2max$. Weight was measured every morning after voiding but before breakfast. Subjects started the 24-hour urine and fecal collections on PRE. In the afternoon of PRE, volunteers participated in a laboratory familiarization session. During that session, each volunteer exercised on the treadmill for several short, 10-15 minute, bouts at the speeds and grades calculated to elicit 35%, 50%, 75%, and 80% of $\dot{V}O_2max$. Additionally, each volunteer cycled at the resistance and cadence calculated to elicit an exercise intensity of 50% $\dot{V}O_2max$. The intensities were validated by measurement of respiratory gases via open circuit spirometry (Sensor Medics, 2900z, Anaheim, CA). These sessions served to familiarize the volunteers to the technical personnel, laboratory, instrumentation, and exercise protocol and also to validate the estimated treadmill speeds and grades and the cycle resistance and cadence required to elicit the desired exercise intensities.

As seen in Figure 1, Days 2 through 10 were three repetitions of a three-day pattern of R-day, R-day, E-day. Days of experimental testing (E) were separated by two rest days (R). The daily routine on these non-testing days (R) was less rigorous than on the experimental exercise days (E). Estimated total energy expenditure was approximately 3000 kcal $\cdot d^{-1}$ while the estimated total energy expenditure for each E-day was approximately 4300 kcal $\cdot d^{-1}$. The schedule for each R-day was the same and is presented in Appendix C, Schedule for each Rest Day (R-Day). To summarize briefly, after the morning urine collection, the volunteer had REE measurements taken. Later in the morning and in the early afternoon, each volunteer exercised for one hour, 30 minutes on the cycle ergometer and 30 minutes on the treadmill, at 50% $\dot{V}O_2max$. A brief warm-up preceded each exercise session. These exercise sessions were supervised and exercise intensity was monitored by exercise heart rate. Heart rate was measured (lead I configuration) using a telemetric, wireless heart rate monitor (Polar Pacer, Polar CIC, Port Washington, NY). Intermittent $\dot{V}O_2$ (Sensor Medics, 2900z, Anaheim, CA) measurements were also taken to validate exercise intensity. The volunteers were free for the remainder of those days to participate in light activities (reading, paperwork, pool, movies, etc.) but they remained on the metabolic ward.

On each E-day, days 4, 7, and 10, each volunteer completed the experimental

exercise protocol. This protocol occurred in two sessions separated by a 5 hour rest period. The daily schedule for each E-day was the same and is presented in Appendix D, Schedule for each Experimental Exercise Day (E-Day). The volunteers were closely supervised during the rest periods. The experimental exercise protocol is fully described below (see EXPERIMENTAL EXERCISE PROTOCOL).

On day 11, POST, final measurements were taken: REE, $\dot{V}O_2max$, and DEXA. The procedures for each of these measurements are described in detail in the following sections: RESTING ENERGY EXPENDITURE, MAXIMAL AEROBIC POWER, and BODY COMPOSITION, respectively.

EXPERIMENTAL EXERCISE PROTOCOL

On each of the three E-days during the experimental period, the volunteers performed two prolonged, treadmill exercise tests separated by a five-hour rest and feeding period (Figure 2). All the morning exercise protocols were similar to each other in mode, intensity, duration, and ambient conditions (temperature 16.7±1.2°C, relative humidity 84±7%). The afternoon exercise trials similar to each other in intensity and ambient conditions, however, during the afternoon trials the volunteers participated in a carbohydrate manipulation (see EXPERIMENTAL DIET, **Carbohydrate Supplementation**). Succinctly, the three carbohydrate manipulations, placebo (CHO-0) and two carbohydrate beverage trials (CHO-1, CHO-2), were assigned in a random block design. Additionally, unlike the REP trials which terminated at 120 minutes of exercise, the volunteers were encouraged until run to volitional exhaustion during the afternoon (CHO) trials.

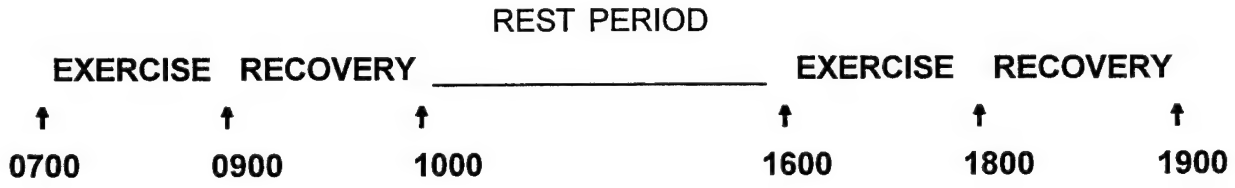

Figure 2. Schematic of the Experimental Exercise Day (E-day)

On each E-day, the volunteer reported to the exercise laboratory after the morning urine collection and body weight. After insertion of the venous catheter (see BLOOD SAMPLING PROCEDURES AND BIOCHEMICAL MEASUREMENTS), the heart rate monitor was positioned (lead I configuration). After a 20-minute postural equilibration, the PRE blood sample was drawn. This and all subsequent blood samples were drawn while the volunteer was standing. Exercise commenced immediately after acquisition of the PRE blood sample.

The three replicate trials (REP-1, REP-2, and REP-3) were conducted approximately from 0700 to 1000 on days 4, 7, and 10 of the experimental period. The volunteers began by walking on a motor-driven treadmill for five minutes at the speed pre-determined (on PRE) to elicit an intensity of 35% $\dot{V}O_2$max. This 5-minute stage served as a warm-up. Speed was then increased to elicit an intensity of 50% $\dot{V}O_2$max until minute 60. At that time the intensity was further increased to 75% $\dot{V}O_2$max and remained at that intensity throughout the second hour of exercise. The REP trials ended at 120 minutes of exercise. A one-hour supervised recovery period began at the cessation of exercise. After the supervised recovery period, approximately 1000 hours, the volunteer was free to return to the metabolic ward where he could change his clothing, eat lunch, and rest until the afternoon exercise trials. Figure 3 is a diagrammatic representation of the morning (REP trials) and afternoon (CHO trials) experimental exercise protocols.

During the REP trails respiratory gases were sampled via open-circuit spirometry using a metabolic cart (Sensor Medics 2900Z, Anaheim, CA). The analyzer was calibrated against gases of known concentrations before each measurement. Respiratory samples were collected for five-minute intervals at 20-25 minutes and 50-55 minutes when exercise intensity was 50% $\dot{V}O_2$max, 75-80 minutes and 100-105 minutes when exercise intensity was 75% $\dot{V}O_2$max, and during recovery at 20-25 minutes and 40-45 minutes. The first three samples were excluded and the subsequent samples were averaged for each sampling time.

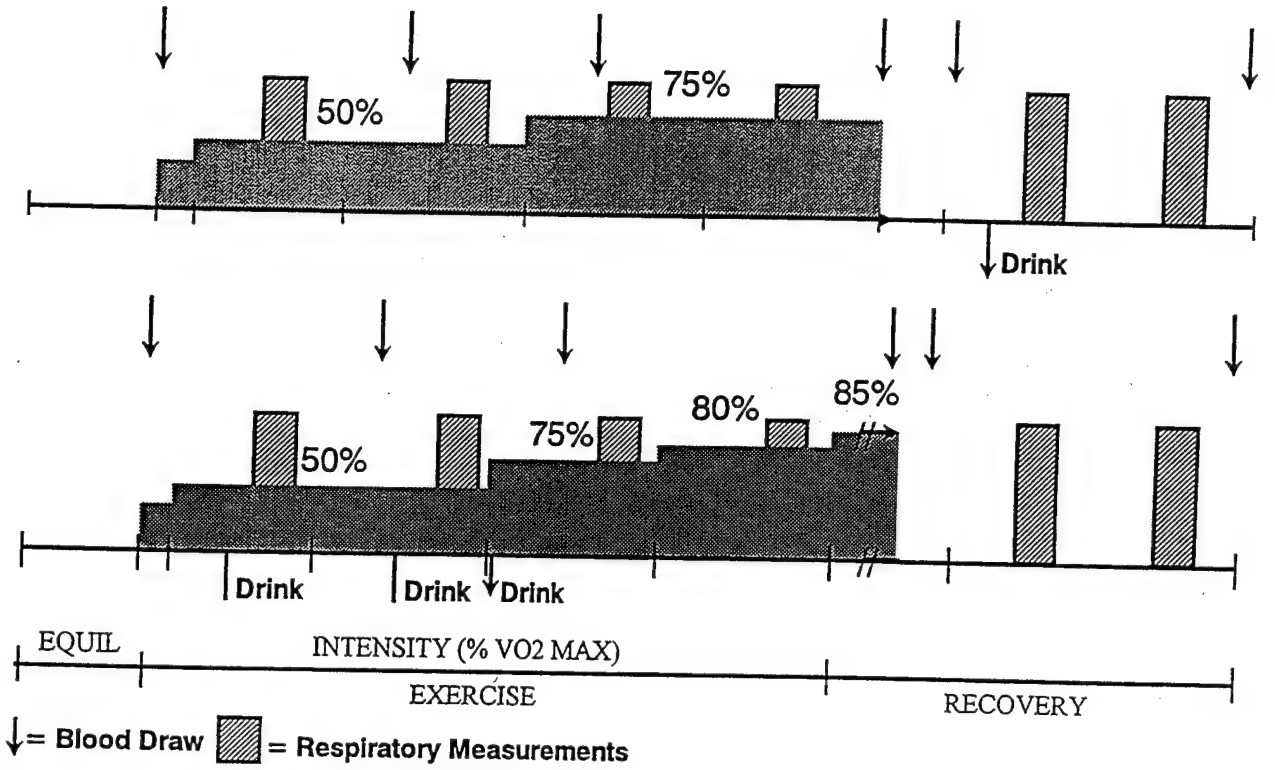

Figure 3. Graphical representation of the morning (REP) and afternoon (CHO) exercise trials where: ↓=blood draw; %=% $\dot{V}O_2max$; "Drink"=time at which the volunteer drank the CHO beverage or placebo.

Heart rate was monitored throughout exercise and recovery using a wireless heart rate monitor (Polar Pacer, Polar CIC, Port Washington, N.Y.). Heart rate was recorded every 10 minutes at the lower intensity exercise and every 5 minutes at the higher intensity.

After the one-hour post-exercise recovery period, the volunteers were free to return to the metabolic ward to shower, change clothing, eat lunch, and rest until the afternoon session. At 0300, the volunteer reported to the exercise laboratory for instrumentation and preliminary measurements. The afternoon exercise protocol was the same as the REP trials until minute 90 when exercise intensity was increased to 80% $\dot{V}O_2$max. At 120 minutes the intensity was further increased to 85% $\dot{V}O_2$max and the volunteer was encouraged to run until volitional exhaustion or until HR or T_{core} reached termination criteria (USARIEM Type Protocol, 1992). During the afternoon exercise sessions, core temperature (T_{core}) was continuously monitored using a telemetry system (CorTemp™) consisting of an ingestible temperature sensor (approximating a vitamin pill in size and shape, 1.3 cm by 2 cm), a plastic-coated, pliant antenna worn by the volunteers in criss-cross fashion across the back and chest, and the data recording system, which was secured to the treadmill and attached to the antenna by a length of wire positioned so as not to impede free movement of the limbs. The afternoon trial results are presented briefly in this manuscript and in greater detail in a separate manuscript (Murphy, 1994).

BLOOD SAMPLING PROCEDURES AND BIOCHEMICAL MEASUREMENTS

Blood samples were obtained from an indwelling teflon™ catheter which was inserted into a superficial forearm vein. The catheter was kept patent with saline throughout the exercise and recovery periods. After a 20-minute equilibration period in the upright posture, blood was acquired immediately prior to exercise (PRE), at 40 (40E) and 70 (70E) minutes of exercise, immediately post-exercise (IP), and at 10 minutes (10R) and 60 minutes (60) of recovery . During the recovery period, the subject walked for 5 minutes, then remained standing for the 5 minutes preceding the first recovery blood sample (10R). The subject was then seated until minute 45 when he stood for a 15 minute equilibration period before the final blood sample (60R).

The biochemical variables determined from blood samples taken during the REP trials (REP-1, REP-2, REP-3) included: lactate, glucose, triglyceride, non-esterified fatty acids, glycerol, β-hydroxybutyrate, insulin, C-peptide, adrenocorticotropic hormone, cortisol, epinephrine, and norepinephrine. Biochemical variables measured during the afternoon exercise trials (glucose, glycerol, insulin and non-esterified fatty acids) are reported elsewhere (Murphy, 1994). Blood for lactate, glucose, free fatty acid, glycerol, insulin, and C-peptide analyses was transferred to plain test tubes. Serum was collected after centrifugation and frozen at -80°C until subsequent analysis. Blood for catecholamine analysis was collected into pre-chilled heparinized test tubes containing 70 μL 10% sodium metabisulfite per 5 mL whole blood. The sample was centrifuged and plasma was frozen at -80°C until analysis. Blood for adrenocorticotropic hormone, hematocrit, and hemoglobin analyses was transferred into pre-chilled EDTA test tubes. Hematocrit and hemoglobin analyses were performed immediately. All biochemical analyses were performed at the Pennington Biomedical Research Institute, Baton Rouge, LA.

Hematocrit and hemoglobin were determined on a Coulter Counter. Changes in plasma volume during exercise were calculated from hematocrit and hemoglobin values using the equations presented by Dill and Costill (Dill, 1974). The calculated percentage change in plasma volume were used to normalize the measured blood constituents for each exercise trial.

Lactate, glucose, triglyceride, non-esterified fatty acids, glycerol, β-hydroxybutyrate, and free fatty acids were analyzed on a Beckman Synchron CX5 automated chemistry analyzer (Beckman Instruments, Brea, CA) using Sigma (Saint Louis, MO) reagents for lactate, β-hydroxybutyrate and glycerol, Beckman (Brea, CA) CX reagents for glucose and triglyceride, and Wako (Denver, CO) reagent for non-esterified fatty acids. All results are reported with a 95% confidence limit.

Insulin was analyzed by microparticle enzyme immunoassay on the Abbott IMx automated immunochemistry analyzer using Abbott (Chicago, IL) reagent. Recovery of spiked samples was 93-106.7%. Inter-assay variance was 3-8%.

C-peptide was determined using commercially available double antibody radioimmunoassay kits from Diagnostic Products Co., Inc. (DPC, Los Angeles, CA).

Recovery was 94-108%. Within and between assay variance was 3.0-5.3% and 1.9%-10.0%, respectively.

Adrenocorticotropic hormone (ACTH) was analyzed using the double antibody radioimmunoassay method (DPC, Los Angeles, CA). Recovery was 93-106%. Intra-assay variance ranged from 3-10% and inter-assay variance was 6-12%.

Cortisol was analyzed by the Coat-A-Count procedure (DPC, Los Angeles, CA). Recovery was 91-110% and inter-assay variance ranged from 4-9%.

Catecholamine analyses were performed by HPLC using an amperometric electrochemical detector using Bio Rad equipment and protocols (Bio Rad Catecholamine System). Recoveries were 102% for epinephrine and 105% for norepinephrine. Intra-assay variance was 3-8% and 3-4% for epinephrine and norepinephrine, respectively. Inter-assay variance was 2-7% for epinephrine and 2-4% for norepinephrine.

EXPERIMENTAL DIET

During the 11-day experimental period the volunteers were fed a weight-maintaining, controlled diet. In the field, SOF soldiers consume a hypocaloric diet (Jones, 1990) and rely on endogenous fat stores to meet energy requirements (Hoyt, 1991). We did not want the volunteers to lose weight, yet, we wanted to simulate, as closely as possible, the diet an SOF soldier would consume in the field. In order to meet those requirements, the experimental diet included the amounts of CHO and protein normally included in a field diet (Jones, 1990) and fat content varied somewhat to meet energy requirements. Thus, the contribution of macronutrients in the experimental diet was as close as possible to a field diet. The major difference was that the source of fat was exogenous rather than endogenous. Carbohydrate was limited to 4 $g \cdot kgBW^{-1} \cdot da^{-1}$. Protein intake was adequate (MRDA), 1.5 $g \cdot kgBW^{-1} \cdot da^{-1}$. Fat content varied slightly based on estimated energy requirements. Total caloric intake varied with BW.

Total caloric requirements for each day of the experimental period were estimated from predicted energy expenditure. A total daily energy expenditure of approximately 4300 kcal was predicted for each E-day. Energy expenditure for the R-days was predicted to be less, approximately 3000 kcal. Energy expenditure required for basal metabolism based on age, gender and surface area is estimated at 38 kcal · m^2 · hour (Altman,1968; Burzstein,1989). DuBois surface area (DuBois, 1916) was estimated at 1.9 m^2 for this population from previous studies (Muza, 1987; Fulco, 1992) With the addition of 10% of the ingested food energy to account for dietary thermogenesis, resting energy expenditure was estimated at approximately 2000 kcal per day. The energy required for light activity and to complete the exercise sessions on R- and E- days was calculated from predictive metabolic equations (ACSM Guidelines, 1991).

Body weight was obtained each morning after urination. Hydration status was closely monitored using fluid-intake/ urine-output logs. Volunteers were encouraged to drink freely to maintain optimal hydration.

A three-day menu rotation (Appendix E) of hot, palatable foods was designed using the Extended Table of Nutrient Values (ETNV) (Moore, 1990). Each food and beverage item was weighed to the nearest 0.01 g on a Mettler balance (PM4000, Hightstown, N.J.). Subjects were strongly encouraged to consume all foods and beverages provided. Unconsumed foods and beverages were weighed back and subtracted from the day's total. The three-day menu rotation corresponded to the three-day R-day, R-day, E-day rotation, so the volunteers received the same daily menu on corresponding days. Caffeine can increase metabolic rate (Higgins, 1915) and exert a differential effect on metabolism dependent on training status (Poehlman et al, 1985). In order to minimize the effects of caffeine on metabolism, the volunteers were asked to restrict their intake of over-the-counter medications and limit intake of caffeinated beverages (coffee, soda, etc.) to one cup or less beginning 10 days prior to their participation in the study. Additionally, caffeine was excluded from the experimental diet, and to allow for wash-out, the first experimental exercise protocols were not conducted until Day 4. Water, caffeine-free and calorie-free beverages were available *ad libitum*.

Carbohydrate Supplementation

In addition to the above diet, a carbohydrate beverage manipulation accompanied the afternoon sessions (CHO-1, CHO-2, CHO-3) of the exercise protocol. The CHO supplement (MALTRIN® M500, Muscatine, IA) was prepared by the Sustainability Directorate (SD), U.S. Army Natick Research, Development and Engineering Center (USANRDEC), Natick, MA. Each subject participated in three experimental conditions: CHO-0, CHO-1, and CHO-2. The treatments were taste-tested at USANRDEC prior to the experimental testing and no discernable differences were noted between treatments. To mask the subtle differences in texture among the treatments, the drinks were served over ice. In order to control for order/training effects, the assignment of CHO treatments followed a single-blind, random block design. With three CHO treatments, there were six possible permutations of the treatments and, with 18 subjects, three iterations of the six permutations were possible. Each volunteer was randomly assigned to one of the permutations. The composition of all three drinks is presented in Appendix F.

CHO-0 was the placebo treatment. It was similar to the other solutions in flavor and color. The placebo was consumed at the same time points as the carbohydrate treatments: 10 minutes after the completion of the morning exercise session and three times during the afternoon exercise session at 20, 40, and 60 minutes.

In the CHO-1 trial, subjects consumed a CHO solution containing 2.2 g CHO·kg BW^{-1} 10 minutes after completion of the morning exercise session. During the afternoon exercise session, a similarly flavored and colored placebo was consumed three times at 20, 40, and 60 minutes of exercise.

In the CHO-2 trial, subjects consumed a CHO solution containing 1 g CHO·kg BW^{-1} 10 minutes after completion of the morning exercise session. During the afternoon exercise session, a CHO solution containing 0.2 g CHO·kg BW^{-1} was consumed three times at 20, 40, and 60 minutes.

Total CHO intake was identical for trials CHO-1 and CHO-2. Total volume of solutions consumed for all three trials was dependent upon body weight. The

concentrations of the CHO beverages consumed after the morning and during the afternoon exercise trial were 11% and 25%, respectively. Water was available *ad libitum* throughout the exercise sessions and during recovery. Water consumed during the experimental protocol was measured and recorded.

BODY COMPOSITION

Height, Weight, Percent Body Fat

Pre-test vertical height was measured in duplicate to the nearest 0.1 cm using a stadiometer (Holtain, Ltd., Crosswell, Wales). Semi-nude body weight was measured every morning after the subject had voided, but before breakfast, using an electronic scale (model 6800, Cardinal Detecto, Brooklyn, N.Y.) accurate to $\pm$0.1 kg. On days 1 and 11 bone mineral content and soft-tissue mass were measured using dual energy x-ray absorptiometry (DEXA) (Hologic QDR-2000, Hologic Inc., Waltham, MA) (Mazess, 1990). Percent body fat was determined from the DEXA analysis.

Somatotype

The somatotype of each subject was determined on day 1 by the methodology previously described by Heath and Carter (1967). The measurements required for determination of somatotype included: body weight, height, selected skinfolds, selected joint breadths and selected circumferences. The skinfold sites measured included: triceps, subscapular, suprailiac, and calf (Harpenden Skinfold Calipers, H.E. Morse Co., Holland, MI). Femur and humerus breadths and calf and bicep circumferences were measured at the appropriate sites (Gulick Measuring Tape, Country Technology, Inc., Gays Mills, WI). From the measurements listed above, a rating for each somatotypical component, i.e., ectomorphy, mesomorphy, endomorphy, was calculated.

Fatiguability

Fatiguability of the quadriceps muscle group demonstrates a positive linear

correlation ($r=.86$ $p<0.01$) with percent fast twitch (FT) muscle fibers (Thorstensson et al. 1976). In order to non-invasively assess muscle fiber composition, a fatiguability test was performed on PRE according to the protocol described by Thorstensson, et al (1976). Briefly, volunteers performed 50 consecutive, maximal full knee extensions, i.e., from 90° to 0°, on an isokinetic dynamometer. The mean decline in peak muscular force during 50 contractions as a percent of initial peak force represented fatiguability (Thorstensson and Karlsson, 1976).

MAXIMAL AEROBIC POWER ($\dot{V}O_2max$)

A continuous, treadmill exercise protocol was employed to elicit $\dot{V}O_2max$ (Costill and Fox, 1969). After a 3 minute warm-up at 1.56 $m \cdot sec^{-1}$ (3.50 miles per hour) and 0% grade, the speed was increased to 2.50 $m \cdot sec^{-1}$ for 3 minutes (0% grade). The grade was maintained at 0% for the following 3 minute stage while the speed was increased to 3.35 $m \cdot sec^{-1}$ (7.50 miles per hour). Thereafter, the speed was constant at 3.35 $m \cdot sec^{-1}$ (7.50 miles per hour) while the grade was increased every 2 minutes beginning with a 4% grade, until $\dot{V}O_2max$. Respiratory gas exchange was continuously collected via open circuit spirometry (Sensor Medics, 2900Z, Anaheim, CA). Previously established criteria were used to determine attainment of physiological $\dot{V}O_2max$ (Thoden, 1982). Before each exercise test, the metabolic carts were calibrated using gases of known concentrations.

NITROGEN BALANCE

Nitrogen balance was calculated according to the formula:

Nitrogen balance = N intake - (urine N + Fecal N + Sweat N + Blood N)

Subjects began precisely-timed 24-hour urine and fecal collections at 0600 on day 1 and ended at 0600 on day 11. During the three experimental exercise protocol days (4,7,10) sweat composition was determined from serial sweat collections obtained using a previously described method (Bergeron, 1993; Verde, 1982). Total sweat loss during exercise was the difference in pre and post body weights with adjustments for

fluid intake and urine excretion during the exercise sessions. Nitrogen lost in the blood samples was estimated using the value of 34.3 g N · L blood^{-1} (Lentner, 1984). The nitrogen content of urine, feces, and sweat were measured by the chemoluminescence method (Antek Chemiluminescent Nitrogen analyzer, Model 703C, Antek Instruments, Houston, TX).

RESTING ENERGY EXPENDITURE (REE)

Resting gas exchange measurements were made on PRE, POST and all R-days. Measurements were made within the first 30 min of waking and were performed at the same time of day for each subject between the hours 0600 and 0800. Subjects were at least 12-hour postabsorptive. Measurements were made in a darkened, quiet, thermally comfortable environment with the subject supine, motionless, and awake. Metabolic measurements ($\dot{V}O_2$ and $\dot{V}CO_2$) were collected using a portable metabolic cart with a ventilated hood system (SensorMedics, 2900z, Anaheim CA). Subjects breathed through a clear plastic, ventilated hood which was sealed at the neck by means of a plastic collar. A pump pulled room air through the hood at a continuous rate and all gases were directed to the mixing chamber. Before each test session the metabolic cart was calibrated against gases of known composition. Standard metabolic variables were then derived from the concentration differences between inspired and expired O_2 and CO_2 and the measured flow rate. The values for the last 10 min of the 30 minute session were averaged. Resting energy expenditure (REE) and respiratory quotient (RQ) for this 10 min period were calculated using the equations derived by Weir (Weir, 1949).

STATISTICAL ANALYSES

Statistical analyses of the data include the calculation of means, standard deviations, and coefficients of variation. Intra-individual variation was defined as the coefficient of variation (CV) of values for the same subject repeated under the same conditions (REP-1, REP-2, and REP-3). The coefficient of variation for the group of all subjects at any given point represented inter-individual variation. Analysis of variation was used to compare intra- to inter-individual variation for each variable over time (α=0.05).

Multi-way analysis of variance on hormone and metabolite concentrations was used to determine if there were significant differences between resting, exercise and recovery values. Newman-Keuls post hoc analysis was used in the presence of significant differences ($p<0.05$).

RESULTS AND DISCUSSION

EXPERIMENTAL DIET

Table 2 summarizes the mean daily macronutrient intake during the 11-day experimental period. The percent total caloric intake coming from carbohydrate, protein, and fat and were 37%, 13%, and 50%, respectively. Mean caloric intake was 3657 ± 225 Kcal $\cdot$ da^{-1}. The experimental diet was designed to mimic a field diet as closely as possible. In a survey of eleven field studies, Jones et al. (1990) reported that soldiers consume approximately 300 g CHO $\cdot$ da^{-1} in the field. This daily intake of carbohydrate is less than the 400 g $\cdot$ da^{-1} recommended by the Committee on Military Nutrition (Department of the Army, 1985) and less than the 400 to 450 g $\cdot$ da^{-1} (or up to 70% of total caloric intake) commonly recommended by coaches to their athletes (McArdle et al, 1991). This low CHO intake underlies a transition to a fat-predominant metabolism. The shift from a CHO- to a fat-predominant metabolism does not appear to impede low intensity physical activity. Gray, et al. (1990) reported no reduction in muscle glycogen levels in physically active males who had consumed a high fat diet for a three-week experimental period and had previously reported a 30% increase in endurance performance at 65% $\dot{V}O_2$max in swine adapted to a high fat diet (Gray, 1988). Additionally, Phinney *et al* (1983) have reported maintenance of aerobic endurance performance (65% $\dot{V}O_2$max) in cylists on a eucaloric ketogenic diet for four weeks. However, although endurance performance was maintained, results of that study strongly indicate that exercise performance at higher intensities would be dramatically reduced approximating a "throttling of function near $\dot{V}O_2$max" consequent to the ketoadaptation which limited carbohydrate utilization. CHO must be available as an energy substrate for optimal high intensity performance. The impact of CHO availability vs. carbohydrate depletion on high intensity exercise has been previously demonstrated and reported (Bergstrom, 1967; Coyle, 1983; Coyle, 1986) and is supported by the $\dot{V}O_2$max data presented in this report (see MAXIMAL AEROBIC POWER). Further, the CHO experiment conducted during the afternoon exercise trials of this research project demonstrated a significant improvement in run time-to-exhaustion for both CHO treatments (Murphy, 1994).

Table 2. Mean daily macronutrient intake over the 11-day experimental period.

	$g \cdot da^{-1}$	$g \cdot kgBW^{-1} \cdot da^{-1}$
CHO	327±34	$4g \cdot kgBW^{-1}$
PRO	118±13	$1.5g \cdot kgBW^{-1}$
FAT	201±9	$2.5g \cdot kgBW^{-1}$

BODY COMPOSITION

Weight, Percent Body Fat

As seen in Table 3, there were no discernable changes in body weight nor percent body fat from PRE to POST. Individual data are presented in Appendix G.

Table 3. Mean body weight and percent body fat pre and post experimental period.

	PRE	**POST**
BW*	83.2±8.7	82.9±8.5
% Body Fat	18.6±5.8	17.8±6.6

* BW=body weight

MUSCLE FATIGUABILITY TEST

Mean decline in peak muscular force, fatiguability, during 50 maximal leg extensions demonstrates a positive linear correlation ($r=.86$, $p<0.01$) with percent fast

twitch (FT) muscle fibers (Thorstensson et al. 1976). The limitations of this methodology for determination of muscle fiber composition are well known, however, this non-invasive methodology is suitable for descriptive purposes within the context of this investigation. Based on the decline in peak muscular force, the volunteers had a mean of 57.1 ± 0.2% fast twitch (FT) muscle fibers in the *m. vastus lateralis* with a range extending from 40.4% to 78.5% FT. Fourteen of the seventeen volunteers had over 50% fast twitch fibers, and, of that number, 8 were over 60% FT and 3 were over 70% FT. Individual fatiguability results are presented in Appendix H. These results indicate that the SOF soldier has a greater percent FT muscle fiber composition than is found in the general population. This finding is consistent with the high degree of mesomorphy and increased capacity for physical work demonstrated by these volunteers.

SOMATOTYPE

Figures 4-6 are graphical presentations of somatotype data. The three axes of the graph represent the three components describing physique: endomorphy, mesomorphy, and ectomorphy. The relative contributions of each component to the somatotype increases as the point approaches the labeled end of the axis. Figure 4 presents the mean somatotype of the volunteers participating in this study and, for purposes of comparison, the somatotypes of previously reported male Olympic athletes and a reference male non-athlete (deGaray, Levine, Carter 1974). The mean somatotype of the SOF soldier-volunteers was very close to the somatotype of U. S. football players and demonstrated a similar degree of muscularity as Olympic ice hockey players, middle/heavy weight boxers, and gymnasts. The SOF soldier is more similar in physique to the Olympic athletes presented in this comparison than to the reference male.

Figure 5 compares the mean somatotype of the SOF soldier-volunteers in this study to the mean somatotypes reported for a group of 48 U. S. Navy Sea Air Land (SEAL) operators and 39 U. S. Navy Basic Underwater Demolition/SEAL (BUD/S) school graduates (Beckett, 1989). The reference male non-athlete is also presented. In this comparison, the similarity in muscular development among the three groups of

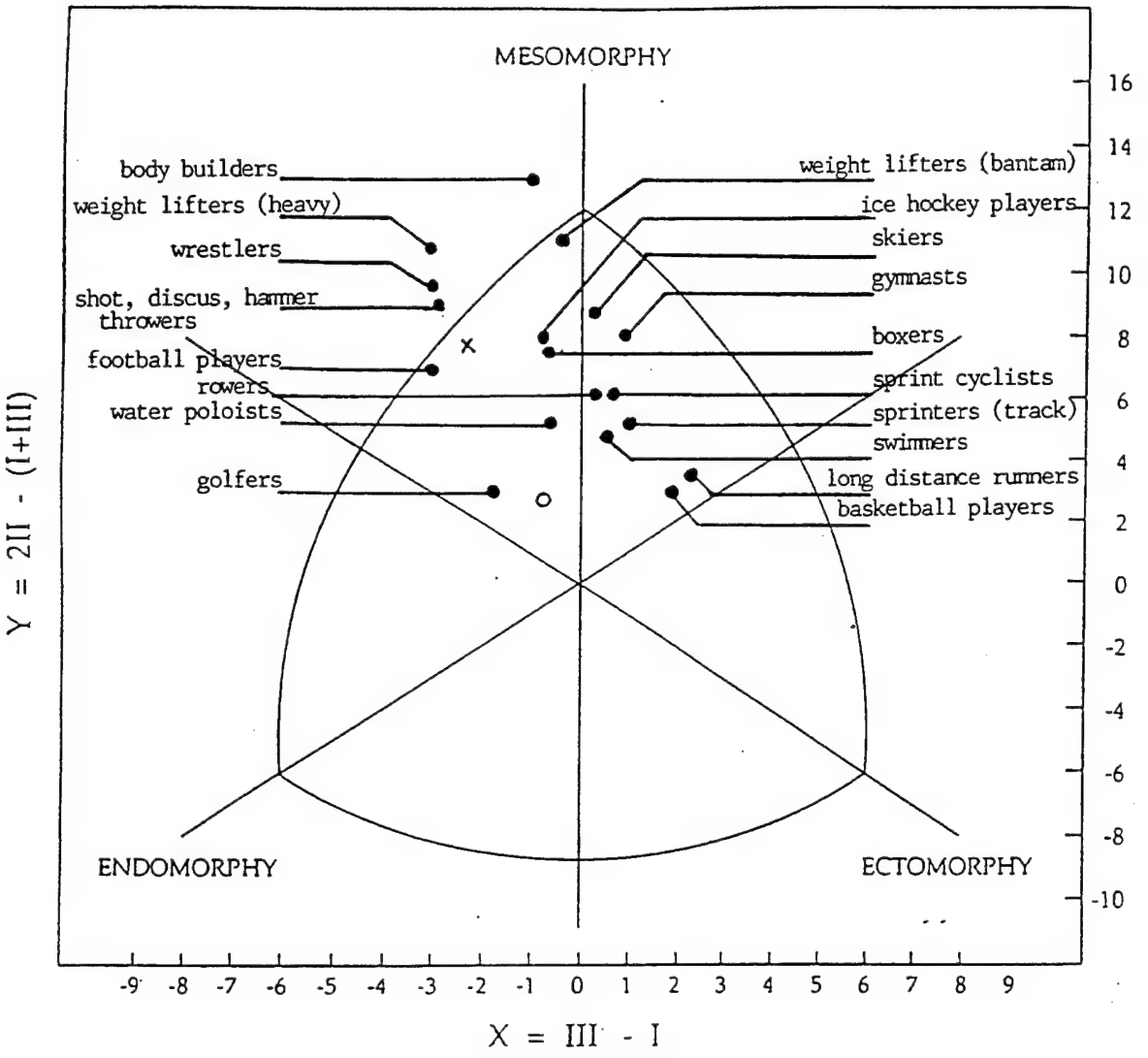

Figure 4. Mean somatotype of the SOF soldier-volunteers participating in this study compared to the mean somatotypes for various male Olympic athletes and a reference male non-athlete (deGaray, et al, 1974) **X**=SOF soldier-volunteers (n=18); ●=male Olympic athletes; O=reference male non-athlete.

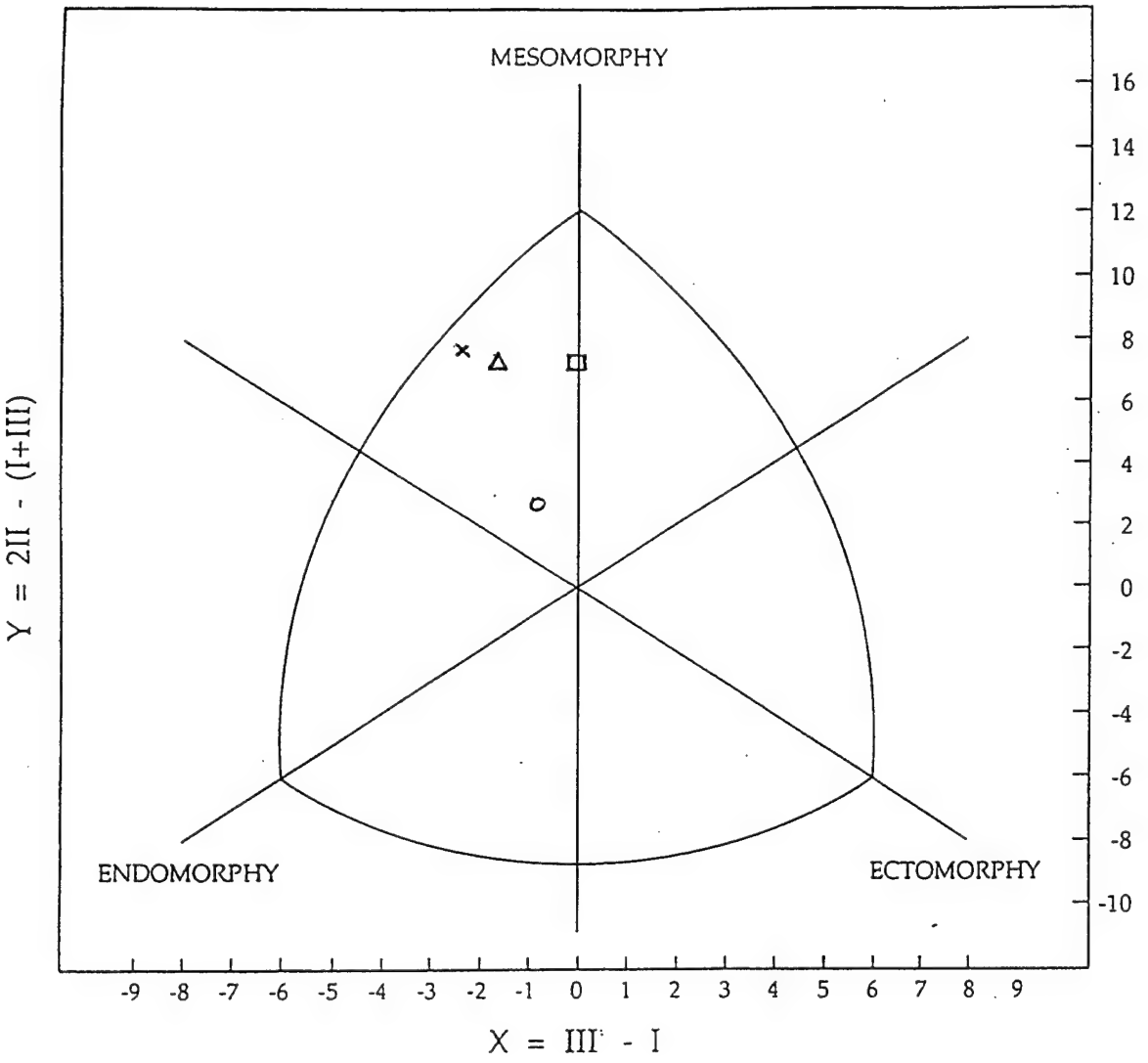

Figure 5. Graphical comparison of the mean somatotypes of U.S. Army SOF soldiers, U.S. Navy BUD/s graduates, U.S. Navy SEAL/SDV operators, and a reference male: **X**=SOF soldier-volunteers (n=18); □=U.S. Navy BUDs graduates (n=39); ▵ U.S. Navy SEAL/SDV operators (n=48); O=reference male non-athlete.

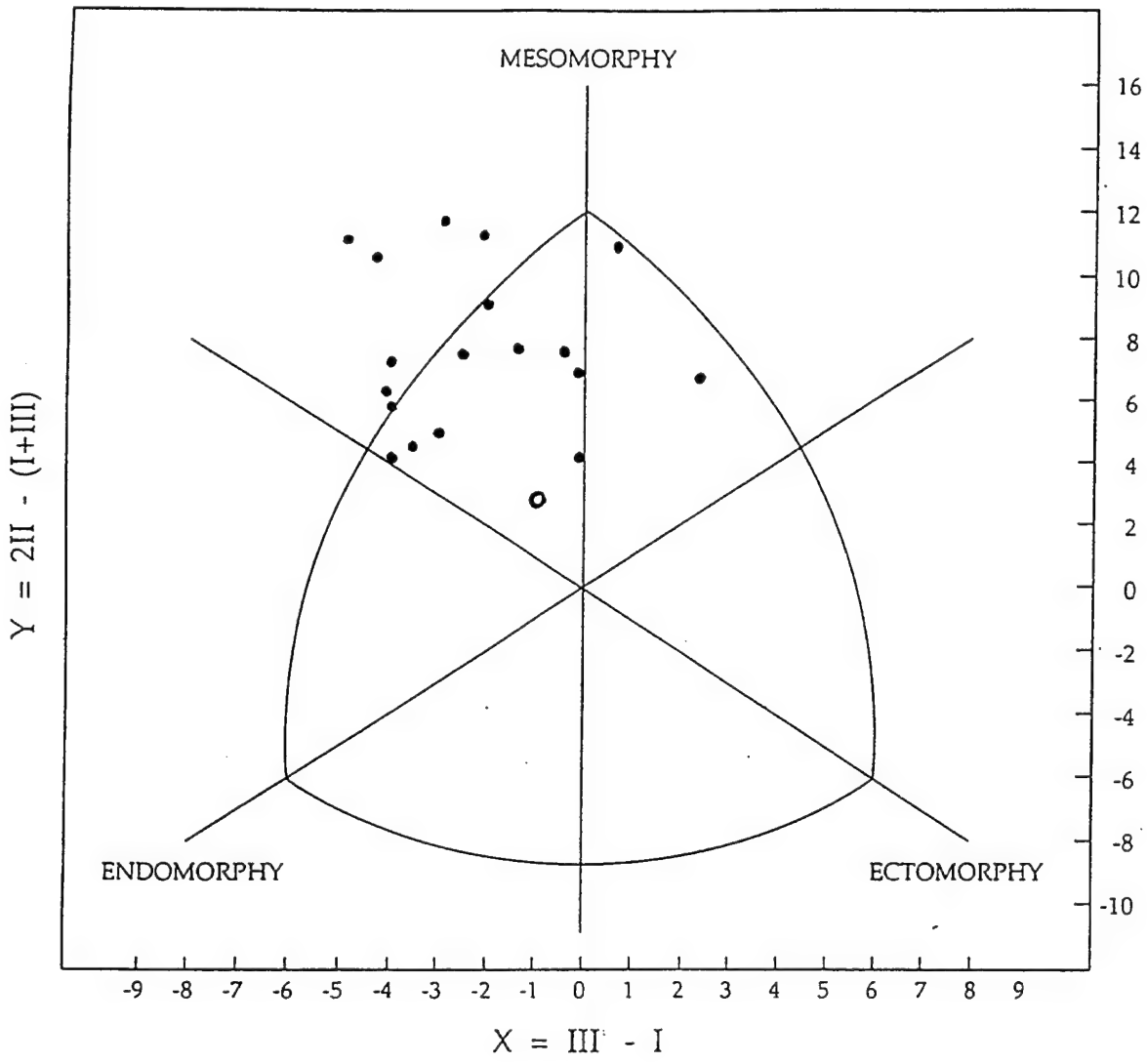

Figure 6. Individual somatotypes of the eighteen SOF soldiers participating in this study: ●=U.S. Army SOF soldiers; O=reference male non-athlete.

Special Forces Operators is striking. The U.S Army SOF soldiers were slightly more muscular than both Navy groups and also had slightly more body fat. Differences in training status and age may contribute to differences in body fat among the groups. Measurements for the BUD/S school graduates were taken in the three weeks prior to their graduation from the physically rigorous six month training program. Although the elite soldier maintains a high degree of physical fitness (Gabarée, 1994), the training imposed during this school is extremely strenuous. Additionally, the recent BUD/S school graduates were younger (22.3 + 2.4 yrs) than both the SEALs (25.9 + 4.4 yrs) and the U.S. Army SOF soldier-volunteers (30.3 + 3 yrs).

Individual somatotypes of the eighteen SOF soldier-volunteers participating in this study are presented in Figure 6. The volunteers were from two active "A" teams. Although there was some diversity in physique, sixteen of the eighteen volunteers were in the same sector, demonstrating the same degree of muscularity as many Olympic athletes. There was more diversity in endomorphy (fatness) and ectomorphy (thinness, linearity) than in mesomorphy (muscularity). Although there were no statistical differences between the teams, it appears that members of team 1 clustered higher on the vertical axis indicating a higher degree of muscularity. Eight members of team 1 were higher in mesomorphy than six members of team 2. Since the members of a team are likely to train together, training regimens are more similar within teams than between them. It is reasonable to suggest that differences in physical training may underlie the differences in physique between teams.

Table 4 summarizes the mean somatotypes for the elite military operators compared in this manuscript and the reference male non-athlete. Individual somatotype data are presented in Appendix I.

Table 4. Mean somatotypes of the elite military operators compared in this manuscript and a reference male non-athlete (deGaray, Levine, Carter 1974).

	Endomorphy	Mesomorphy	Ectomorphy
U.S.Army SOF	3.8	6.5	1.5
U.S.Navy BUD/S	2.1	5.9	2.0
U.S.Navy SEALs	2.7	5.9	1.8
Reference male	3.5	4.6	2.8

MAXIMAL AEROBIC POWER

As shown in Table 5, $\dot{V}O_2$max did not change from PRE to POST. Despite maximal efforts by the volunteers, they did not reach the same maximal heart rate (HR_{MAX}) nor did they attain as high an R-value during the POST $\dot{V}O_2$max test as in the PRE test. The attenuated R-value at $\dot{V}O_2$max indicates limited carbohydrate utilization. Clearly, the volunteers were physically unable to achieve the same level of maximal performance, determined by HR_{MAX}, on the POST day despite a manifested training effect (see TRAINING EFFECT) over the experimental period. The arduous experimental exercise protocol was completed the evening before the POST $\dot{V}O_2$max. Although muscle glycogen samples were not obtained, it is reasonable to assume that both hepatic and intramuscular glycogen stores were reduced at the time of the POST $\dot{V}O_2$max test because of the previous day's exercise (Bergstrom, 1967) and the experimental diet (McArdle, 1991; Phinney, 1983) which was not adequate to replenish endogenous carbohydrate stores. This decrement in physical performance supports the contention that performance of high intensity exercise at optimal levels requires adequate accessible CHO. Although the high fat diet characteristically taken to the field by SOF soldiers may not impair physical performance at low intensities, high to moderate intensity exercise requires adequate CHO for optimal performance. In order to optimize nutritional support for the field, intensity and duration of physical activity must be considered. Individual $\dot{V}O_2$max, HR_{MAX}, and maximal R-values ($R\text{-value}_{MAX}$) are presented in Appendix J.

Table 5. Mean PRE and POST Maximal Oxygen Consumption ($\dot{V}O_2max$), Maximal Heart Rate (HR_{MAX}), and Maximal R-Value ($R\text{-}VALUE_{MAX}$).

	PRE	POST
$\dot{V}O_2max$ ($L \cdot min^{-1}$)	4.29 ±0.50	4.25 ±0.40
HR_{MAX} (bpm)	189 ±7	180 ±5
R-value ($\dot{V}CO_2/\dot{V}O_2$)	1.15 ±0.05	1.06 ±0.06

TRAINING EFFECT

Although there was no manifested increase in $\dot{V}O_2max$ after the 11-day experimental period, the volunteers did exhibit a training effect evidenced by a significant decrease in HR between REP-1 on day 4 and REP-3 on day 10 before exercise (PRE), at low (50% $\dot{V}O_2max$) and moderate (75% $\dot{V}O_2max$) exercise intensities, and during the one hour supervised recovery period. This training effect is clearly demonstrated in Figure 7.

The volunteers exercised at 50% $\dot{V}O_2max$ 2 hours each day of the experimental period, except PRE and POST. The R-day (days 2, 3, 5, 6, 8, 9) exercise consisted of 2 exercise sessions, one in the morning and one in the afternoon. Each session consisted of 30 minutes of treadmill walking at 50% $\dot{V}O_2max$ and 30 minutes of cycling at 50% $\dot{V}O_2max$. The exercise performed on the E-days (day 4, 7, 10), consisted of 2 sessions, as well, and, the first hour of each session was treadmill exercise at 50% $\dot{V}O_2max$. After the first hour, exercise intensity was increased in both the morning (REP) and afternoon (CHO) trials. It is known that training is mode- and intensity-specific. The preponderance of exercise over the experimental period was performed at 50% $\dot{V}O_2max$. The decrease in HR at rest and during exercise is a clear manifestation of physical training.

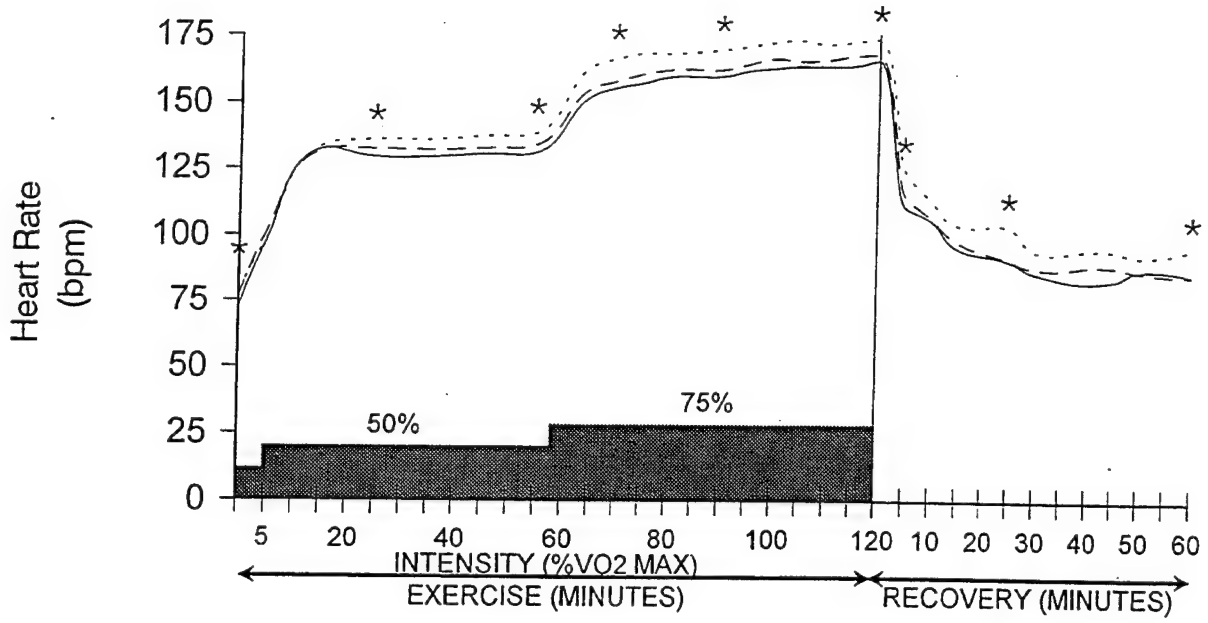

Figure 7. Exercise heart rate; dotted line=REP-1, dashed line= REP-2, and solid line= REP-3, * =REP-1 different ($p<0.05$) from REP-3.

RESPIRATORY EXCHANGE RATIO (R-VALUE)

Use of the term "respiratory quotient" (RQ) is based on the assumption that the $\dot{V}O_2$ and $\dot{V}CO_2$ measurements reflect respiratory gas exchange from cellular metabolism. Another term, Respiratory Exchange Ratio (R-value), is generally used to describe the ratio of $\dot{V}CO_2$ to $\dot{V}O_2$ under conditions, including exercise, which might alter this ratio. Although previous work has demonstrated good agreement between R-value and RQ determined from A-VCO_2 and O_2 differences under steady state exercise conditions, (Essén, 1977; Jansson, 1980; Jansson, 1982), the term R-value will be used in this report.

R-value at Rest

In response to the high-fat diet, resting R-value declined over the experimental period as shown in Figure 8. R-value decreased significantly ($p < 0.05$) from 0.86 ± 0.05 on PRE to 0.82 ± 0.04 on Day 2. From Day 2 to Day 8 R-value continued to decline, although not significantly (0.82 ± 0.04, 0.80 ± 0.05, 0.78 ± 0.04, 0.77 ± 0.04, 0.76 ± 0.04, respectively). This reduction in resting R-value indicates a greater reliance on fat as an energy substrate. Variation between individuals, defined by the coefficient of variation (CV) for the group of all volunteers at any given point, represented inter-individual variation. CV was very low and ranged from 3.9 % to 5.7%. This very low variation between individuals in resting R-value over the experimental period indicates that, despite differences in body composition and physical training, all the volunteers made the transition from a carbohydrate to a fat-predominant metabolism in the same time course. It is interesting to note that CV steadily declined from 5.7% on PRE to 3.9% on day 9.

R-value During Exercise

Respiratory gases were collected for 5-minute intervals at 20-25 and 50-55 minutes of exercise, when the intensity was 50% $\dot{V}O_2$max and at 75-80 and 100-105 minutes when intensity was 75% $\dot{V}O_2$max. During the one-hour recovery period, respiratory gases were sampled at 20-25 and 50-55 minutes. The R-values during the

REP trials (Figure 9) demonstrated a stepwise decrease over the experimental period. This pattern is clear at 20-25 min (day 4: 0.82±0.04; day 7: 0.81±0.03; day 10: 0.79±0.02) and 50-55 min (day 4: 0.81±0.04; day 7: 0.80±0.30; day 10: 0.79±0.03). At the higher intensity (75-80 min and 100-105 min), R-value decreased from day 4 to day 7 and remained the same on day 10 as on day 7 (day 4: 0.87±0.04; day 7: 0.85±0.03; day 10: 0.85±0.03 and day 4: 0.87±0.04; day 7: 0.85±0.03; day 10: 0.85±0.03). Although this decrease was not statistically significant, it may be physiologically significant and represent a continued adaptation to the high-fat diet and low intensity exercise training. On each day of the experimental period, except PRE and POST, the volunteers exercised for 2 hours at 50% $\dot{V}O_2$max. Previous animal and human research has demonstrated that a low intensity exercise stimulus coupled with a high fat diet will induce a greater reliance on fat as an energy substrate (Gray, 1988, 1990; Phinney, 1983). Additionally, and perhaps more importantly, a number of studies have demonstrated a greater reliance on fat as an energy substrate consequent to a carbohydrate inadequate diet (Bergstrom, 1967; Hultman, 1989; Jansson, 1982). The decrease in R-value at rest (Figure 8) and during exercise (Figure 9) indicates that a transition to a greater reliance on fat metabolism occurred over the experimental period. From these data it is not possible to distinguish the effect of the high-fat diet from that of the exercise training. It is likely, however, that the interaction of the diet and exercise serve to augment the metabolic effect that either would have had alone.

Variation in R-value within the same individual and between individuals during exercise is of particular interest in this research effort. Intra-individual variation in R-value during exercise (ie., CV in R-value for the same volunteer at each measurement time 20-25, 50-55, 75-80, and 100-105) over the experimental period was extremely small and ranged from 2.3% to 2.5%. This low variation in the same individual over time includes the metabolic effects of both physical training and diet as well as measurement error. Inter-individual variation in R-value during the REP trials (CV in R-value for the group of volunteers at each measurement time 20-25, 50-55, 75-80, and 100-105 min) ranged from 2.5% to 4.9% and demonstrated a consistent decreasing pattern across the experimental period (Table 6). The control exercised over diet and activity over the experimental period contributed to the decrease in CV. Inter-individual variation barely exceeded intra-individual variation. This extremely small variation between individuals is a clear indication that despite differences in pre-experimental diet, training, and body composition among this group of SOF operators, metabolic

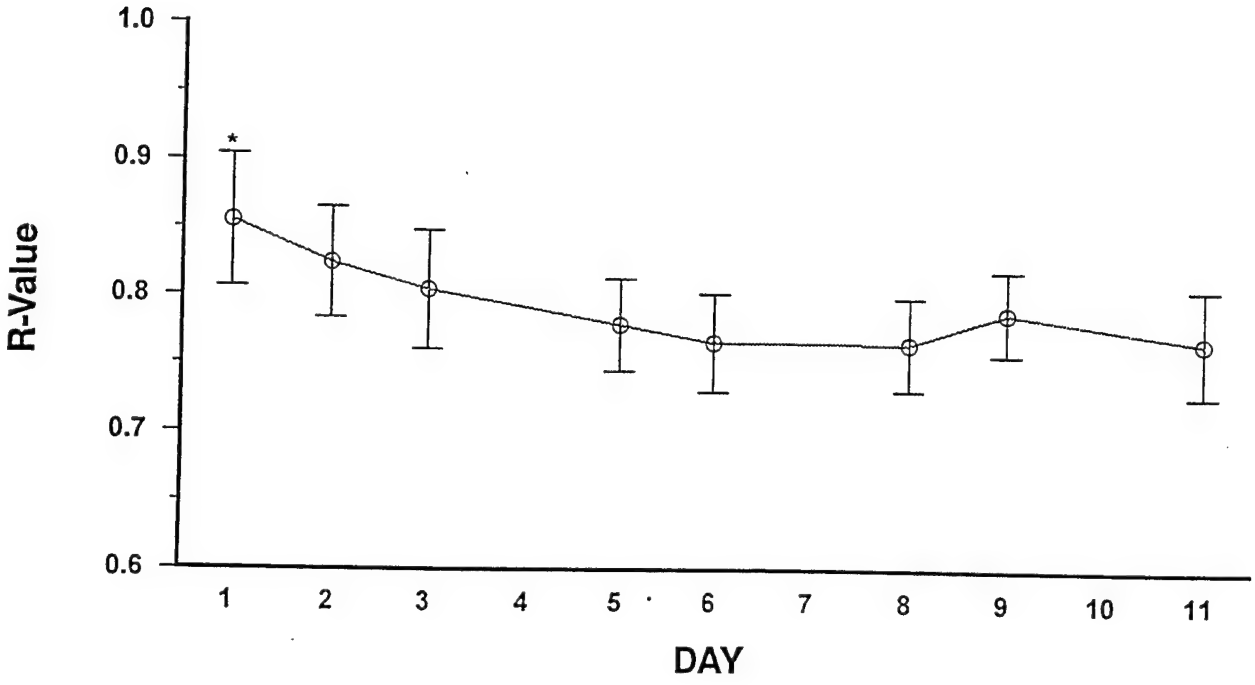

Figure 8. R-value ($\tilde{X} \pm SD$) at rest over the 11-day experimental period; * =day 1 higher than all succeeding days ($p < 0.05$).

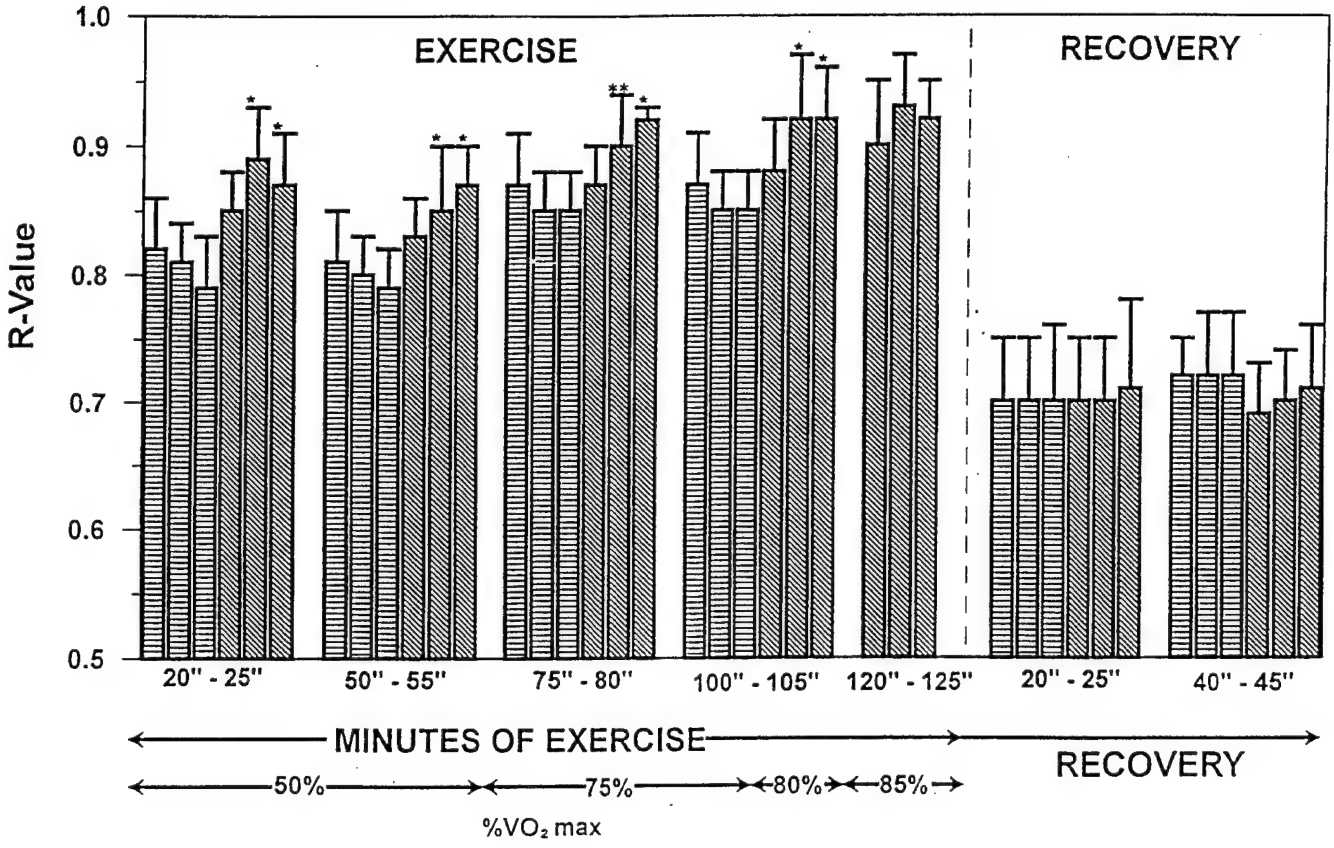

Figure 9. R-values ($\bar{X}$ ± SD) during exercise (REP and CHO trials); horizontal stripes=successive REP trials, diagonal stripes=successive CHO trials, *=CHO-2 and CHO-3 different ($p<0.05$) from CHO-1.

differences, per se, were negligible. The clear implication, then, is that optimal nutrition for the field may be planned on basis of predicted total energy expenditure, predicted exercise intensity and duration and environmental conditions without regard for individual metabolic differences.

Table 6. Coefficient of variation (CV) in R-value for the group of volunteers at each measurement time during the REP trials.

	20-25 min	50-55 min	75-80 min	100-105 min
REP-1 (Day 4)	4.9%	4.9%	4.6%	4.6%
REP-2 (Day 7)	3.7%	3.8%	3.5%	3.5%
REP-3 (Day 10)	2.5%	3.7%	3.5%	3.5%

As stated previously, the results from the afternoon trials (CHO-0, CHO-1, CHO-2) are presented in detail in a separate manuscript (Murphy, 1994). However, it is interesting and pertinent, here, to present and briefly discuss the R-values during those CHO trials (Figure 9). As expected, the R-values during the CHO-2 and CHO-3 (carbohydrate supplement) trials were higher ($p<0.05$) than during CHO-0, the placebo trial. The R-values during CHO-0 at each measurement time (20-25, 50-55, 75-80, and 100-105 min) were not significantly higher than the REP trials, even though the morning trials (REP) were performed after an overnight fast and the afternoon trials were performed after a lunchtime meal and afternoon snack. Of particular interest is the inter-individual variation, CV in R-value for the group of volunteers during the CHO trials at each measurement time. CV ranged from 1.1% to 5.7%. Since the ingestion of the CHO supplement during the CHO-1 and CHO-2 trials caused a significant increase in R-value at each measurement time, this low CV indicates that the volunteers responded to the supplement similarly.

NITROGEN BALANCE

Since body weight and body composition did not change pre- to post-study (Table 3, Appendix G), it may be assumed that energy balance was maintained over the experimental period at approximately 3657±225 Kcal $\cdot d^{-1}$ or 45.7g $\cdot$ kgBW$^{-1} \cdot d^{-1}$.

Daily nitrogen balance for the 10-day period is shown in Figure 10. Day 1 was significantly different from all other days and day 3 was significantly different from days 7, 8 and 9 ($p<0.05$). The initial decline in nitrogen balance may represent the adaptation to the experimental diet (Young, 1986). As demonstrated by the scatterplot in Figure 9, despite the control over diet and energy expenditure, nitrogen balance varied considerably between the volunteers. Inter-individual variation, CV for the entire group for each day was 42% on day 1 and ranged from to 144% to 1256% on days 2 through 10 (Appendix K). Intra-individual variation, CV for each volunteer over the course of the study ranged from 92% to 1362%. In a study comparing protein metabolism in carbohydrate-loaded and glycogen-depleted subjects, Lemon et al (1980) observed an increase in the inter-individual variability in serum urea nitrogen and urine urea nitrogen during exercise in the carbohydrate-depleted condition as compared to the carbohydrate-loaded condition. This increase in variation between individuals in nitrogen metabolism under conditions of inadequate carbohydrate reserves and heavy exercise reflect individual differences in the utilization of protein as an energy substrate. Although muscle biopsies were not obtained in this study, it is reasonable to contend that the intramuscular and hepatic glycogen stores of these volunteers were reduced after Day 4 because the exhaustive exercise performed on each E-Day (Days 4, 7, and 10) was of sufficient duration and intensity to deplete glycogen stores (Bergstrom, J., 1967; Hultman,1989). Furthermore, the diet of 4 g CHO $\cdot$kgBW^{-1} did not provide sufficient CHO for complete restoration of endogenous carbohydrate stores. Restoration of pre-exercise levels of muscle glycogen generally requires 48 hours after prolonged, exhaustive exercise. This time course requires adequate, 60-70%, dietary carbohydrate. If dietary carbohydrate is limited and/or if rest is inadequate, the time course for restoration of pre-exercise glycogen levels will be extended. The time course for complete restoration of endogenous glycogen varies between individuals. Some individuals may require as many as 5 days. The volunteers in this study performed exhaustive physical exercise on each E-Day (Days 4, 7, and 10) and

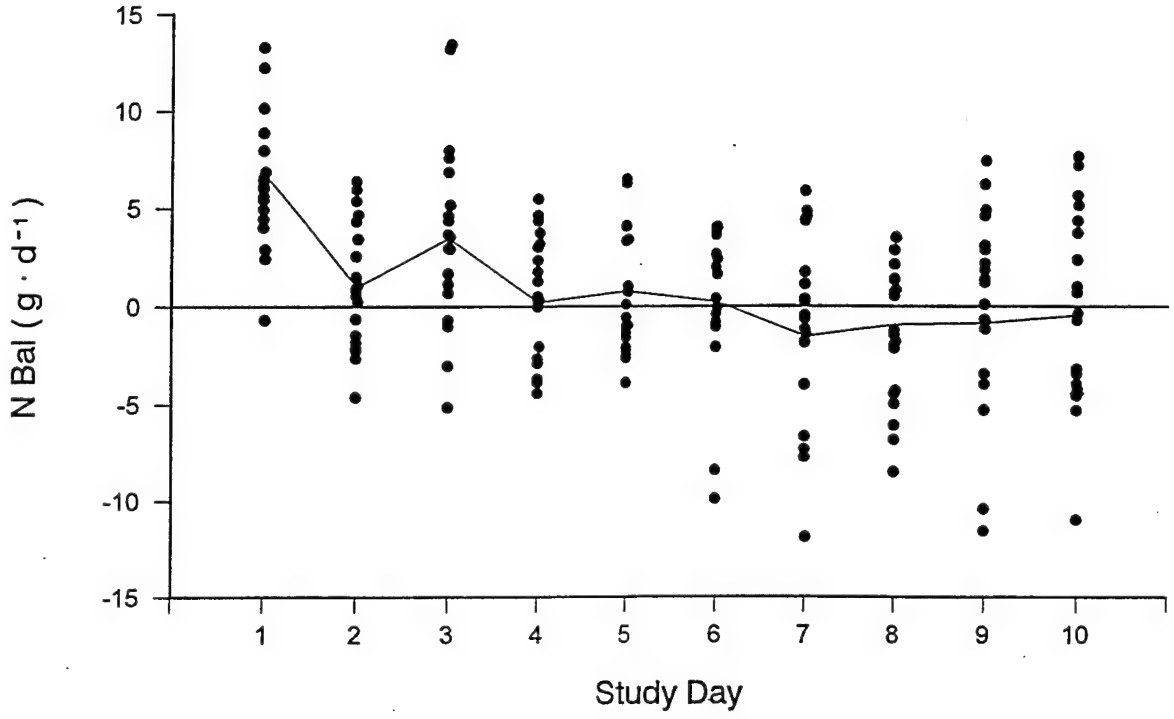

Figure 10. Nitrogen balance over the experimental period; dots=individual values, solid line=mean values.

prolonged (2 hours) low-moderate intensity exercise on all the intervening days. This pattern of physical activity combined with the effects of the experimental diet which provided only 4g CHO · kg BW · da^{-1} (327± 34 g CHO · da^{-1}; 37% total caloric intake) was not adequate to replenish endogenous carbohydrate stores (McArdle, 1991; Phinney, 1983). Consequently, amino acids may have contributed as an energy substrate to supply CHO via gluconeogenesis. The large inter-individual variation in nitrogen balance in this study may be consequent to the interactive effects of the high-fat diet and intense exercise protocol on nitrogen metabolism.

It is of particular interest that mean nitrogen balance was negative on Days 6 through 10. All 17 volunteers were in positive nitrogen balance on PRE. On Day 2, seven of the seventeen volunteers were in negative nitrogen balance. On Day 3 there was an improvement in nitrogen status, only 4 of the seventeen volunteers were in negative nitrogen balance and the mean for the group was positive, 3.50. On Day 4, the first E-day, 7 volunteers were in negative nitrogen balance and the trend was an increase in the number of volunteers in negative balance from 7 on Day 4 to 9 on Day 5, 9 on Day 6, 10 on Day 7, 10 on Day 8, 8 on Day 9, and 9 on Day 10 (Appendix K).

Although these volunteers were physically fit at the initiation of the experimental protocol, there was a demonstrated training effect (see TRAINING EFFECT). Dohm et al. (1977, 1980) have observed an increase in amino acid oxidation and an increase in urea nitrogen excretion in response to exercise training in animal models (Dohm, 1977; Henderson, 1985). Numerous authors have subsequently observed oxidation of amino acids, particularly the branched-chain amino acids, proportional to the exercise intensity in human subjects during endurance exercise (Babij, 1983; Lemon, 1980; Lemon,1982; White, 1981). Protein oxidation may contribute 5-30% (Dohm, 1982; Henderson, 1985; Lemon, 1980) of the total energy cost during exercise. This percent contribution of amino acids to substrate oxidation is small compared to the contributions of CHO and FAT, however, this represents a significant proportion of the total daily protein requirement (Evans, 1983; Lemon, 1987; Millward, 1982) and may indicate an increased protein requirement in physically active individuals.

Gonzea et al. (1974) studied nitrogen balance in active male subjects consuming a diet of 1.0 g/kgBW. In this study, nitrogen balance was negative during the exercise

periods and did not become positive even when dietary protein was increased to 1.5g/kg BW. The SOF volunteers in this study consumed 1.5 g PRO ·kg BW · da^{-1}, an amount nearly twice the protein RDA of 0.8 g · kgBW $^{-1}$ · da^{-1} (Recommended Dietary Allowances (RDA) ninth revised edition, 1980) . The MRDA for protein is 100 g · da^{-1} for males and 80 g · da^{-1} for females (Department of the Army, 1985). More than half of these well-trained men were in negative nitrogen balance for 6 days of the 11-day study. It is difficult to determine whether the negative nitrogen balances observed in this study were due to an increased protein requirement *per se* or secondary to a lack of CHO in the diet at this level of energy expenditure.

Conclusions about nitrogen metabolism are restricted by the limitations of balance studies (Young, 1986). Previous studies present strong evidence to suggest that protein requirement may increase with increasing physical activity (Brooks, 1987; Lemon, 1981). Additionally, relative contributions of fat and carbohydrate in the diet may also induce differences in nitrogen requirements (McCargar, 1989), particularly during periods of increased physical activity. A high fat diet in combination with high energy expenditure, a typical scenario for the SOF soldier in the field, may increase protein requirements simply to provide carbon precursors for gluconeogenesis. Since prolonged negative nitrogen balance has implications beyond exercise performance and muscle tissue repair, additional research on the interactive effects of diet and physical activity on protein metabolism are clearly indicated.

BIOCHEMICAL MEASUREMENTS (REP TRIALS)

The central issue in this research investigation is the extent to which individual SOF soldiers differ in substrate utilization during prolonged physical exercise. Generally, like the respiratory data, the biochemical parameters reflect a very consistent response from individual to individual and support the contention that despite differences in body weight, body composition, and physical training there is minimal variation in substrate utilization during exercise of the same relative intensity.

Plasma volume changes

Figure 11 presents the changes from PRE in plasma volume during exercise and recovery during the REP trials. During each trial (REP-1, REP-2, REP-3), plasma volume at 40 minutes of exercise (40E), when intensity was 50% $\dot{V}O_2$max, was essentially unchanged from PRE. At 70 minutes of exercise (70E) and immediately post exercise (IP), plasma volume was significantly reduced during each REP trial; -5.60 ± 5.7%, -4.94 ± 2.98%, -6.47 ± 3.07% at 40E during REP-1, REP-2, and REP-3, respectively and -5.59 ± 4.57%, -5.80 ± 3.20%, -6.69 ± 3.59% at IP during REP-1, REP-2, and REP-3, respectively. Plasma volume returned to PRE levels by 60 minutes of recovery in each case. There were no significant differences at any sampling point between REP trials.

Plasma volume responses reported here are consistent with previously reported data (Gore, 1992; Greenleaf, 1977; Greenleaf, 1979; Greenleaf, 1982); plasma volume was maintained during the first hour of exercise at 50% $\dot{V}O_2$max, decreased significantly during the second hour of exercise at 75%$\dot{V}O_2$max, and returned to PRE levels by 60R. Both the pattern and magnitude of plasma volume responses during exercise and recovery were similar in each trial.

Concentrations of each biochemical variable were corrected for changes in plasma volume.

Lactate (LA)

Lactate values at 40E (1.38 ± 0.45; 1.21 ± 0.47; 1.34 ± 0.20) were not greater than PRE (1.54 ± 0.26; 1.36 ± 0.62; 1.42 ± 0.27) during each REP trial. However, when exercise intensity was increased from 50% $\dot{V}O_2$max to 75% $\dot{V}O_2$max, LA increased significantly. At 70E(2.99 ± 1.56; 2.67 ± 1.42; 3.21 ± 0.84), IP (3.18 ± 1.39; 3.33 ± 1.53; 3.74 ± 1.26), and 10R (2.43 ± 0.94; 2.64 ± 1.34; 2.76 ± 0.65) LA was significantly higher than PRE. As demonstrated in Figure 12, LA response was similar during all three REP trials. At each sampling time during exercise and recovery, there were no significant differences between treatments. As is well known, circulating lactate levels increase exponentially above the anaerobic threshold because of increased reliance on

anaerobic glycolysis for energy production. There were no measurable differences in LA at any sampling point between REP trials. Although metabolic adjustment to the high fat diet appeared to continue over the experimental period (see RESPIRATORY EXCHANGE RATIO), this continued adjustment appears not to have induced any detectable differences in lactate responses at rest, during low or moderate intensity exercise, or recovery.

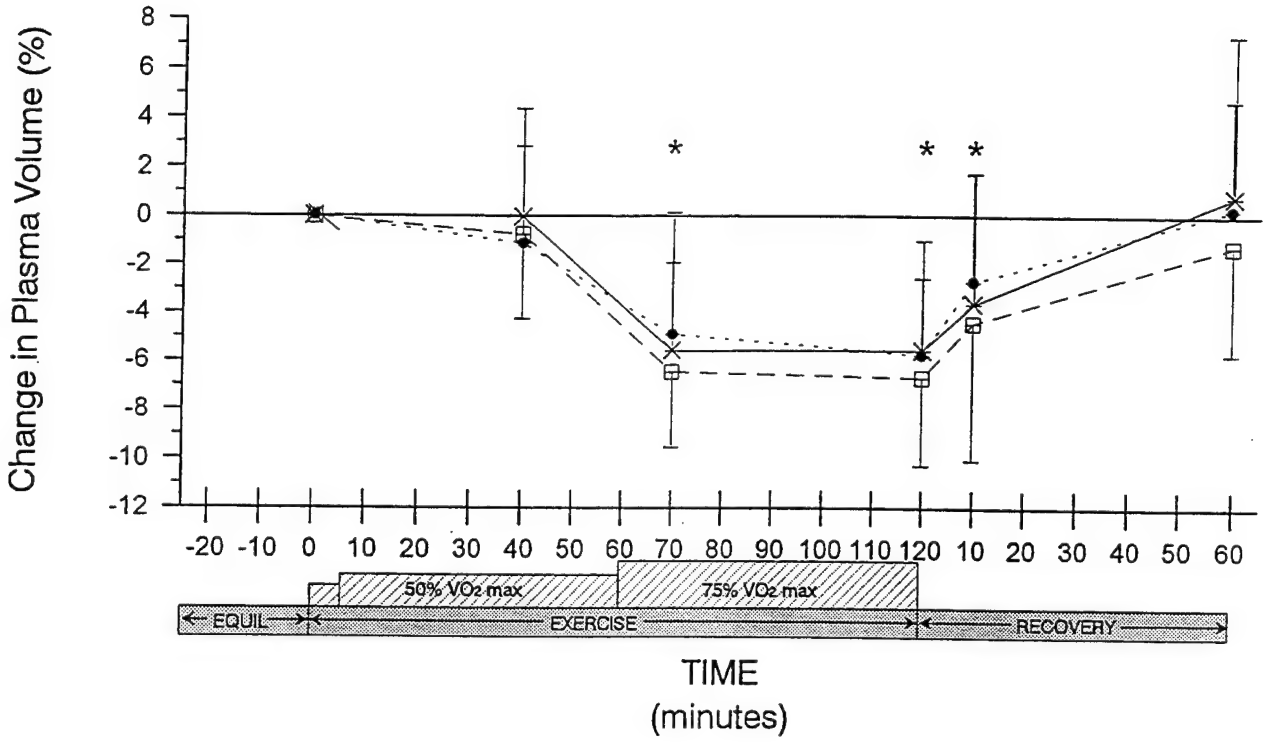

Figure 11. Plasma volume changes ($\bar{X}\pm SD$) during REP trials; X—X=REP-1; ●- -●=REP-2, □---□=REP-3, * =different ($p<0.05$) from PRE.

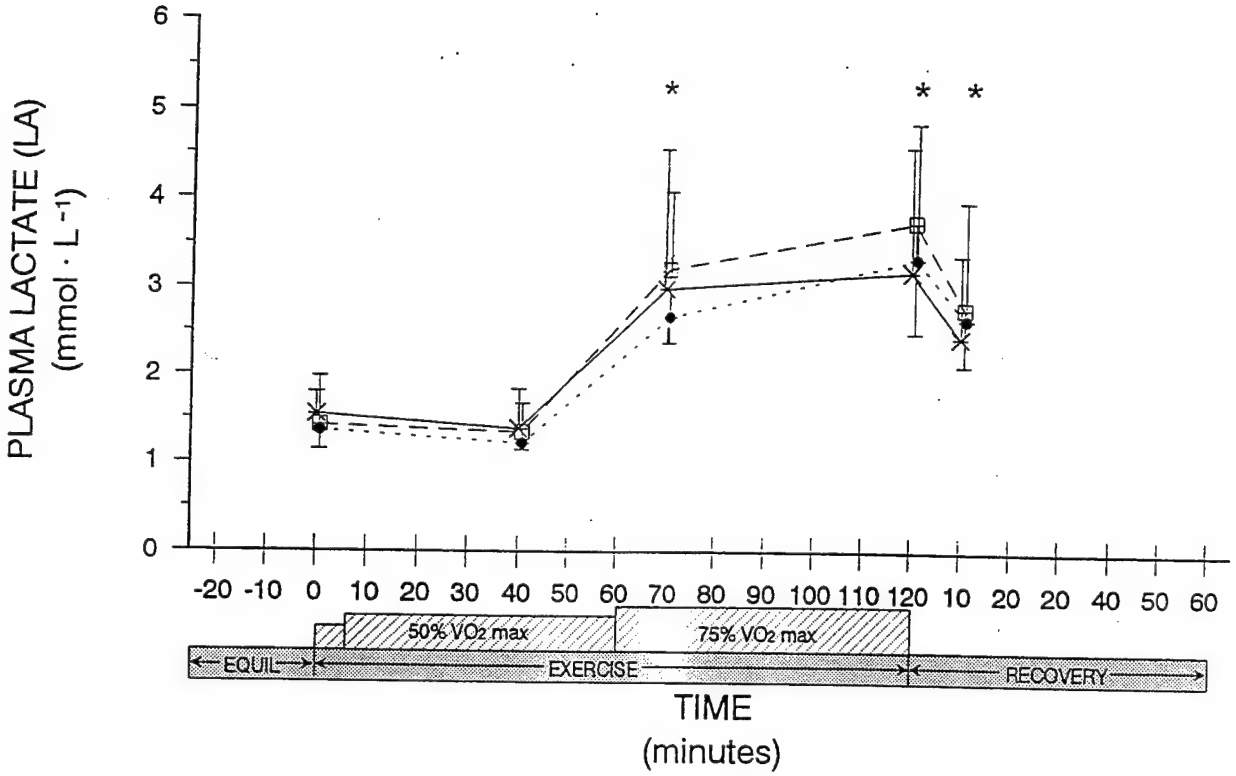

Figure 12. Lactate ($\bar{X}\pm SD$) during REP trials; X—X=REP-1; ●- -●=REP-2, □---□=REP-3, *=different ($p<0.05$) from PRE.

Catecholamines: Norepinephrine (NOREPI) and Epinephrine (EPI)

There were no differences in NOREPI between REP trials at any measurement point (Figure 13). During exercise, NOREPI increased steadily (40E, 70E), peaked at IP and declined thereafter (10R). The magnitude of the increases were slightly higher from PRE to 40E during REP-2 and REP-3 than during REP-1. The 1.91 nmol· L^{-1} increase in NOREPI at 40E during REP-1 was not statistically significant while the PRE to 40E increase during both REP-2 (2.42 nmol· L^{-1}) and REP-3 (2.72 nmol· L^{-1}) increased significantly. The pattern and magnitude of NOREPI response at the higher intensity and during recovery (70E, IP, and 10R) were similar between REP trials NOREPI peaked at IP (14.87±4.96; 14.92±4.06; 13.62±4.59 for REP-1, REP-2, and REP-3, respectively) and declined significantly at 10R (6.50±2.18, 5.49±1.37, 5.44±1.27).

As seen in Figure 13, the pattern of EPI response during each REP trial was similar, i.e., a steady increase from PRE during exercise, peak at IP, and decline at 10R. The magnitude of the responses, however, were different. During REP-1, EPI increased significantly at 70E and IP but the increase at 40E was not significant. During REP-2, EPI was significantly increased at 40E, 70E, IP and 10R. During REP-3 there were no significant increases in EPI. The lack of a significant increase in EPI during REP-3 may be due to the high PRE value for that trial (469.6±282.7) which was significantly greater than the PRE value for the REP-2 trial (225.6±73.1) but not greater than the PRE value for the REP-1 trial (305.3±164.3).

In humans, peripheral plasma levels of NOREPI originate principally from sympathetic (noradrenergic) nerves rather than the medullary cells of the adrenal gland (Galbo, 1983). Previous research has indicated a reduction in NOREPI (Bloom, 1976; Koivisto, 1982) and EPI (Bloom, 1976; Koivisto, 1982; Winder, 1979) responses to the same relative work intensity in trained vs, untrained subjects, however, no consistent training effect has been reported on resting catecholamine levels (Galbo, 1983). The lower NOREPI response at 70 min during REP-2 and REP-3 compared to REP-1 may reflect the exercise training effect. Similarly, the reduced EPI responses during exercise between the REP trials may have been precipitated by the interactive effects of diet and training. A reduction in EPI would serve to attenuate CHO utilization by decreasing glycogen utilization.

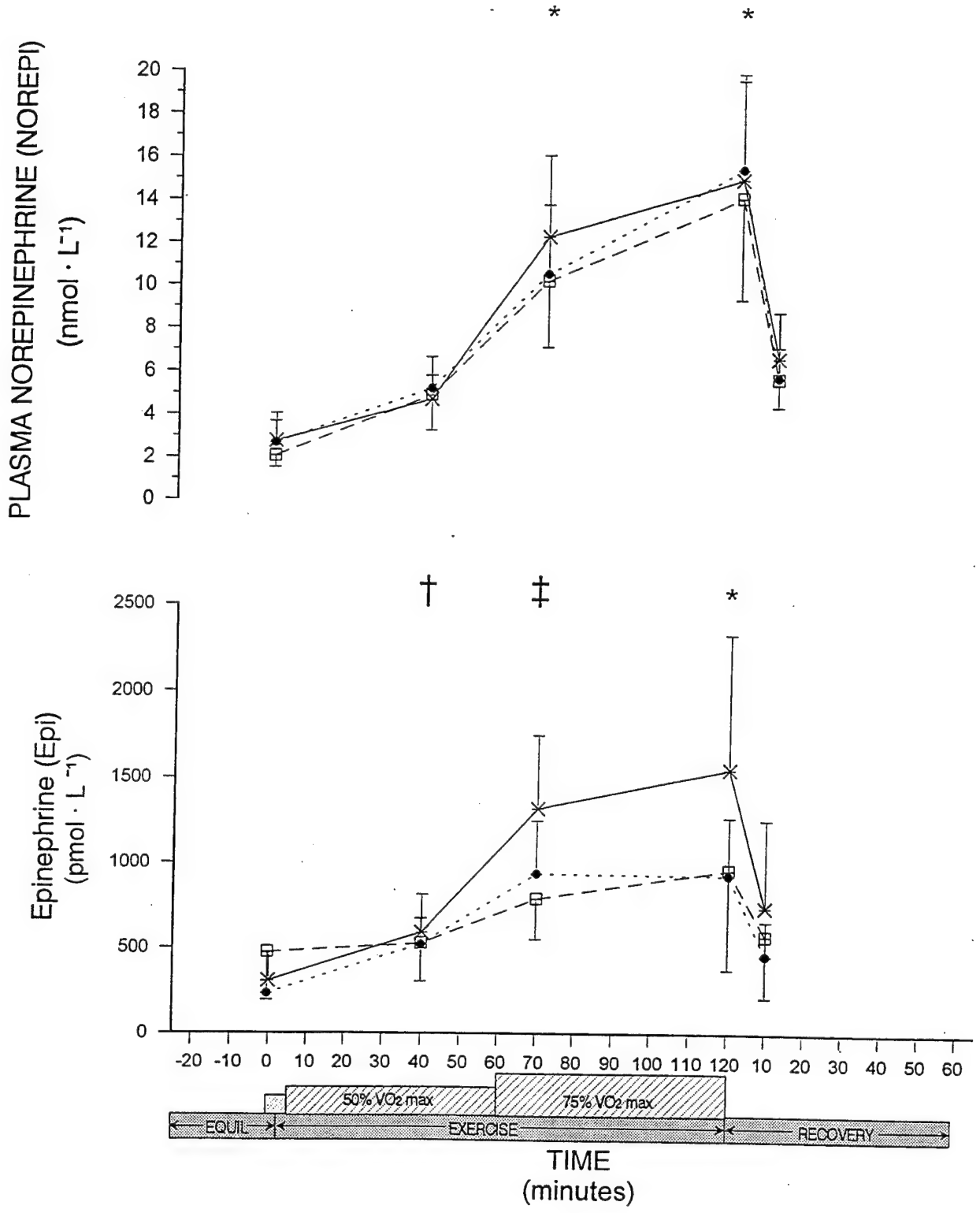

Figure 13. Noreinephrine (NOREPI) and epinephrine (EPI) ($\bar{X}\pm SD$) during REP trials; X—X=REP-1; ●- -●=REP-2, □---□=REP-3, * =different ($p<0.05$) from PRE.

Adrenocorticotropic Hormone (ACTH); Cortisol (CO)

At rest (PRE), ACTH was reduced during the REP-2 (2.74±1.50) and REP-3 (2.55±1.48) trials compared to REP-1 (4.06± 2.28). At 40E and 70E, plasma ACTH decreased during the REP-1 and REP-2 trials while it increased during the REP-3 trial. In a study comparing hormonal responses in trained vs. untrained males, Viru et al. (1992) reported a reduced PRE ACTH and more pronounced response of ACTH in trained vs. untrained men during two hours of cycling exercise at 60% of their pre-determined maximal power output. This pattern observed in the SOF volunteers may be due to physical training. Plasma cortisol decreased during the first hour of low-moderate exercise then increased during the second hour of moderate intensity running. There were no differences in CO at PRE nor were there differences between REP trials in CO at 40E and 70E. At IP and R1, however, REP-1 was significantly higher than REP-2 and REP-3. The reduction in plasma cortisol during exercise may be explained by decreased secretion or increased clearance. Mason (1959) has shown a decrease in adrenocortical activity during prolonged monotonous moderate intensity exercise. Indeed, the intensity during the first hour (50% $\dot{V}O_2max$) may not have been adequate to stimulate increased hypothalamo-pituitary activity. Additionally, Few et al. (1971, 1974) have demonstrated an increase in cortisol elimination during exercise at intensities insufficient to elicit increased cortisol secretion and Few (1974) have demonstrated that a low intensity exercise stimulus increases the uptake of cortisol by the peripheral tissues.

Although the cortisol values IP were not significantly different between REP trials, IP REP-2 and IP REP-3 were lower than IP REP-1 (440.6, 440.3 vs. 537.2, respectively). It is well known that the hypothalamo-pituitary-adrenal axis is highly responsive to exercise intensity and exercise training. The lower CO values at IP during REP-2 and REP-3 may have been due to increased uptake of CO by the peripheral tissues (Viru, 1985) consequent to the observed training effect.

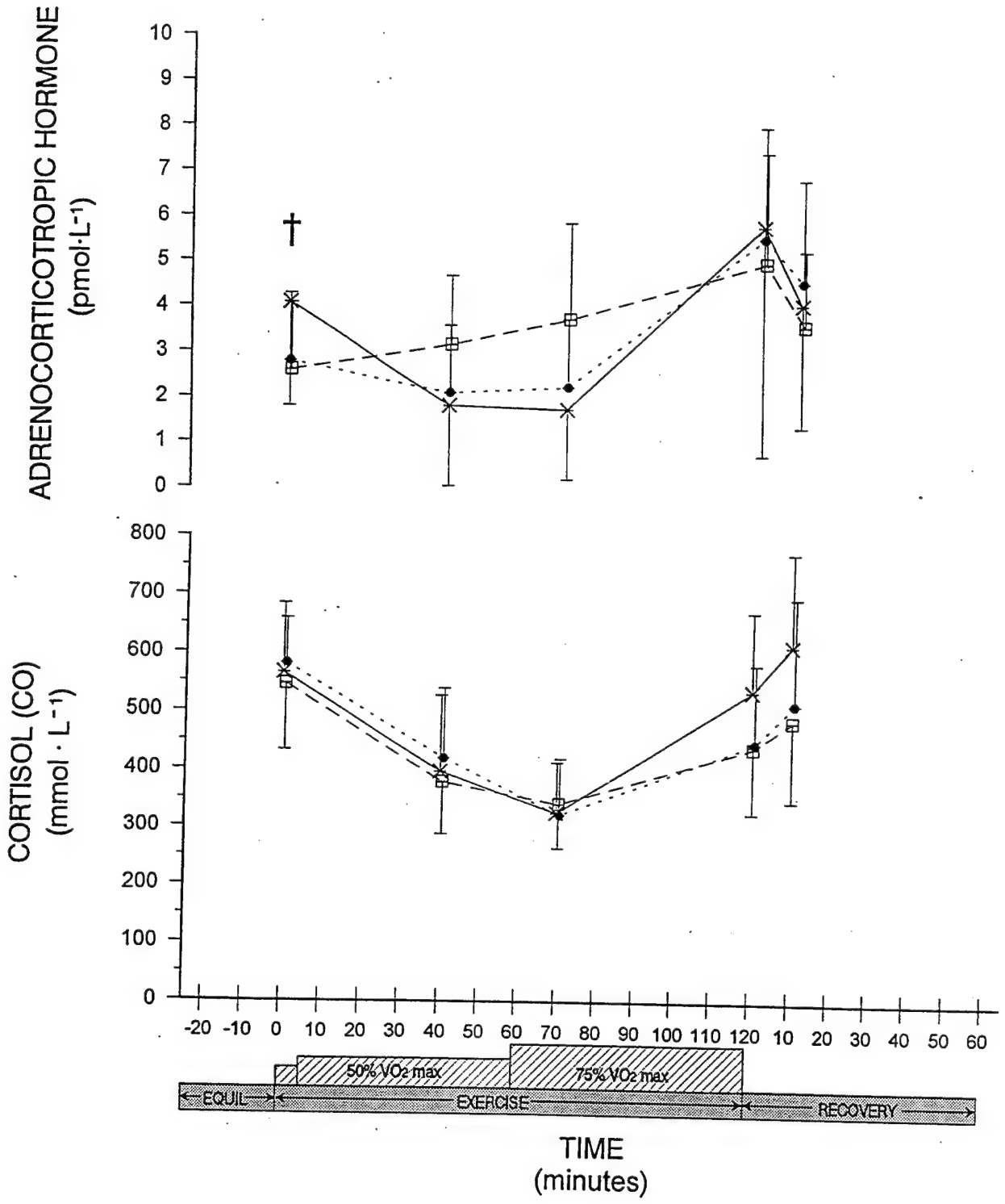

Figure 14. Adrenocorticotropic hormone (ACTH) and cortisol (CO) ($\bar{X}\pm SD$) during REP trials; X—X=REP-1; ●- -●=REP-2, □---□=REP-3, *=different ($p<0.05$) from PRE.

The important observation here is that the pattern of response was similar in this group of volunteers. Pituitary-adrenocortical function is highly variable between individuals and is responsive to many factors including exercise intensity and duration, training status, diet, circadian rhythmicity, and anxiety (Brandenberger, 1976; Sutton, 1988). Despite differences in body composition and training in these volunteers, the responses of these hormones between REP trials were very consistent.

Glucose (GLU) and Insulin (INS)

Blood glucose is normally maintained within a range of 3.89-5.83 $mmol \cdot L^{-1}$ (70-105 $mg \cdot dL^{-1}$)(Young, 1987). As seen in Figure 15, blood glucose was maintained throughout exercise despite limited dietary carbohydrate (EXPERIMENTAL DIET). Although there were no significant differences in GLU between REP trials at rest nor during exercise and recovery, GLU was reduced at IP and R1 in REP-1. It is well known that under conditions of restricted CHO intake or depleted glycogen stores, fatty acids are mobilized from adipose tissue and oxidized by exercising musculature. This increase in fatty acid oxidation decreases glucose oxidation and so, maintains blood glucose levels. It may be that increased fatty acid utilization consequent to the training and diet facilitated the maintenance of blood glucose during exercise in the subsequent trials (REP-2 and REP-3).

There were no significant differences in plasma insulin levels between REP trials at rest nor during recovery. Insulin inhibits glycogenolysis as well as gluconeogenesis. The characteristic decrease in INS during exercise seen in Figure 15 points to a probable increase in hepatic glucose production.

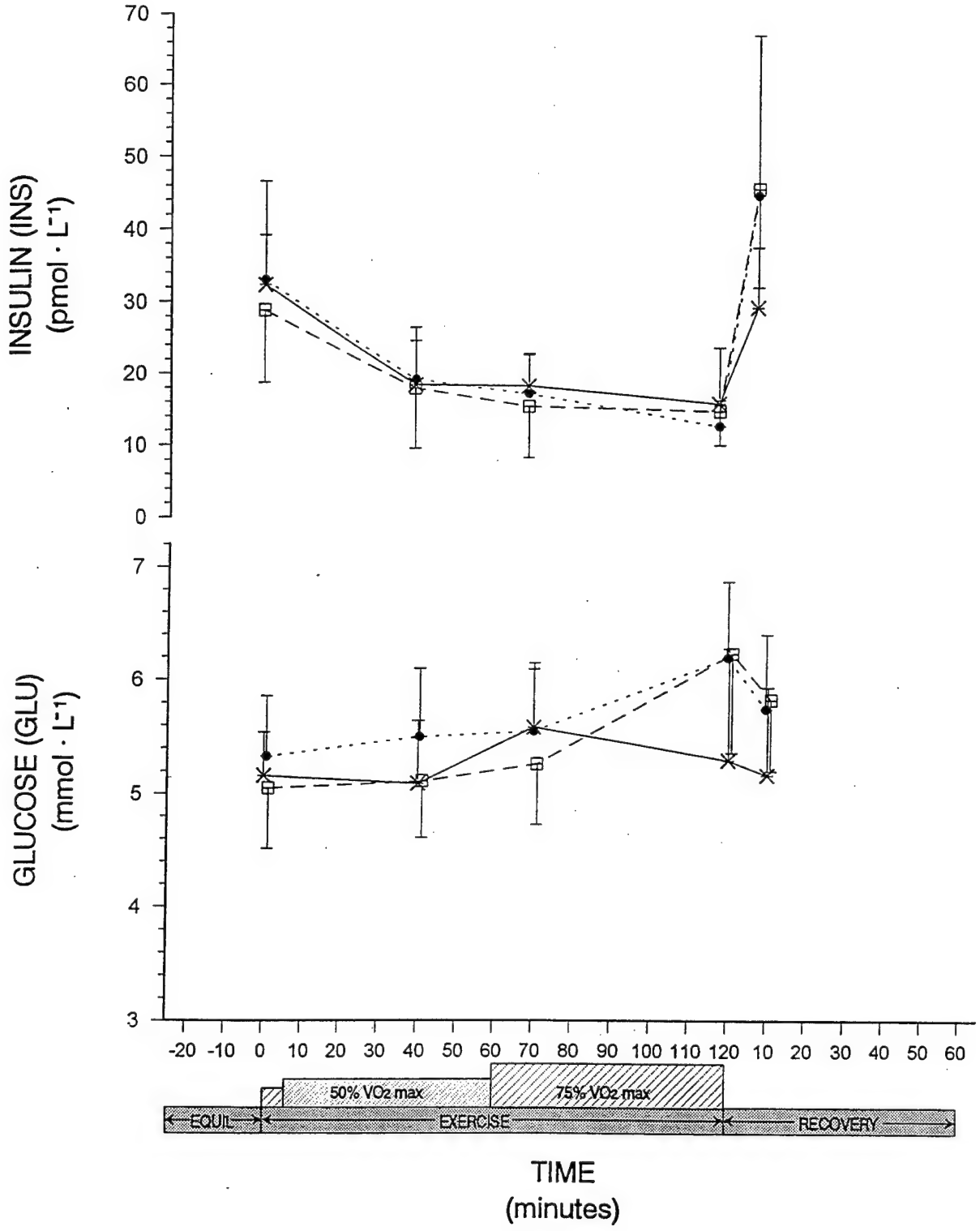

Figure 15. Glucose (GLU) and insulin (INS) ($\bar{X}\pm SD$) during REP trials; X—X=REP-1; ●- -●=REP-2, □---□=REP-3.

Triglyceride (TRIG), Non-esterified Fatty Acids (NEFA), Glycerol (GLY) and Betahydroxybutyrate (βHBA)

As seen in Figures 16-19, the patterns in TRIG, NEFA, GLY, and βHBA responses were similar between REP trials despite an increase in fat utilization evidenced by a decreasing R-value at rest and during exercise (RESPIRATORY EXCHANGE RATIO). Triglycerides were not significantly different between REP trials at PRE, however, they demonstrated a decreasing pattern at PRE over the experimental period; 0.70±0.45 at REP-1, 0.63±0.11 at REP-2, and 0.58±0.21 at REP-3. Although the magnitude of increase during exercise remained the same over the experimental period, there was a consistent decrease in variation between individuals during exercise over the experimental period. The CV at 40E decreased from 52% during REP-1 to 38% during REP-2, and 25% during REP-3. Similarly CV decreased at 70E (40%, 35%, and 27%), IP (35%, 24%, and 20%), and 10R (35%, 28%, and 24%). This pattern of decreasing CV indicates an increasing homogeneity in response among the volunteers.

NEFA (Figure 17) concentration in the plasma is the net difference between release from the adipose tissue and uptake by the exercising musculature. A net change in NEFA represents a change in the balance between these events. Conversely, stability in plasma NEFA values does not indicate that no changes occurred; rather, no net change indicates that the balance between release from the adipose tissue and uptake by the exercising musculature was maintained. Fatty acid mobilization is increased by increases in ACTH, cortisol, epinephrine, norepinephrine, and decreased insulin, all of which occurred from PRE to IP during each REP trial. It appears that the slight adjustments, previously discussed, in these lipolytic hormones over the experimental period were adequate to maintain the balance of NEFA released from the adipose tissue and taken up by the muscle.

There were no significant changes in the pattern or magnitude of GLY (Figure 17) response between REP trials. There were no differences at PRE nor were there differences during exercise. As seen in Figure 18, during each REP trial, GLY increased ($p < 0.05$) at 40E and continued to increase throughout exercise. Unlike NEFA's, GLY is not removed from the plasma by the exercising muscle. The dramatic

increase in plasma GLY, then, is a clear indication of a high rate of lipolysis during exercise. Importantly, variation between individuals was small and did not change over the experimental period.

There were no significant differences in βHBA (Figure 18) between REP trials, however, there was a progressive decrease in the magnitude of change over the experimental period until βHBA values remained stable across the REP-3 trial (PRE, 0.22±0.11; 40E, 0.22±0.09; 70E, 0.23±0.09, IP, 0.27±0.07). Since fat utilization increased over the experimental period (see RESPIRATORY EXCHANGE RATIO), a decrease in βHBA is most likely due to an increase in clearance. The most notable change, however, was a dramatic decrease in variation between individuals over the experimental period. As occurred in TRIG and NEFA, this decrease in variation indicates that the volunteers responded similarly to the diet and exercise challenges.

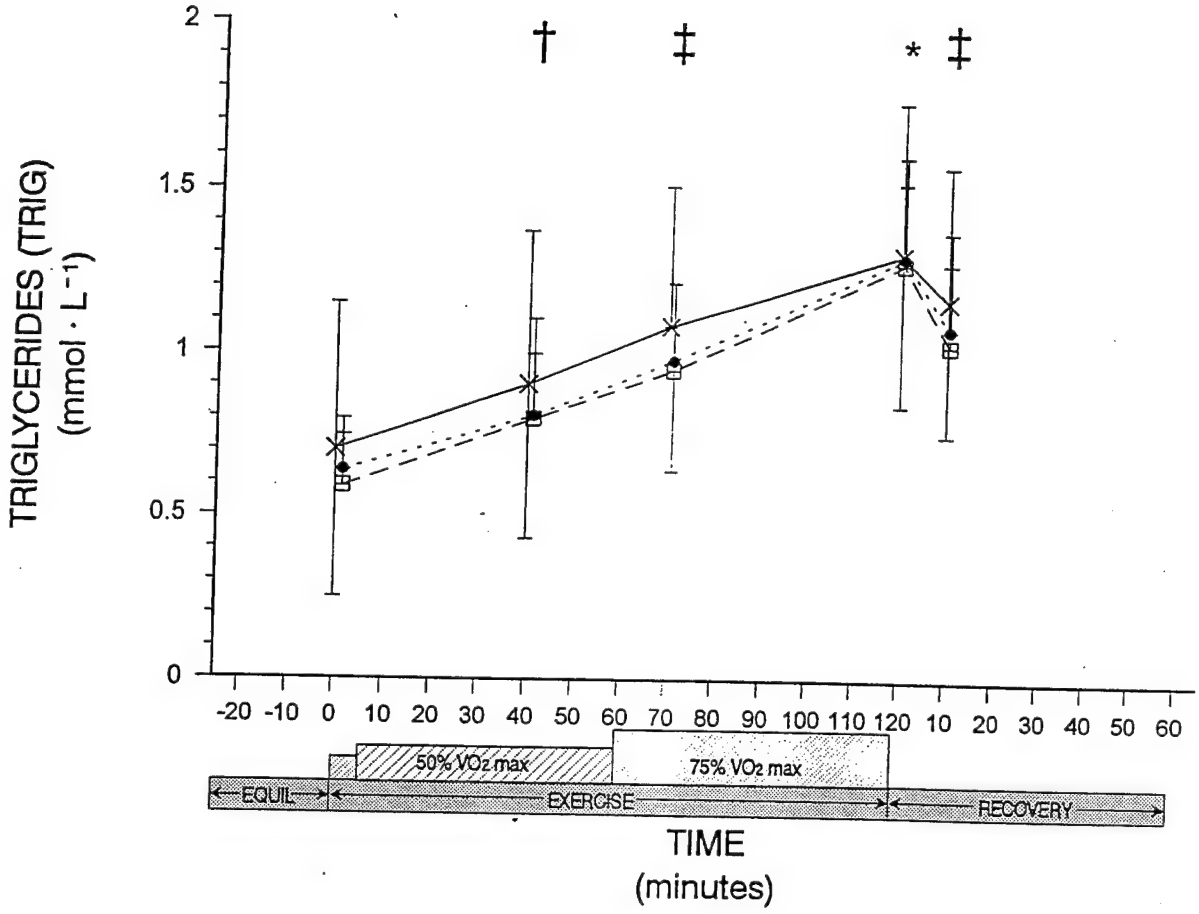

Figure 16. Triglycerides (TRIG) ($\bar{X}\pm SD$) during REP trials; X—X=REP-1; ●- -●=REP-2, □---□=REP-3, *=all conditions different ($p<0.05$) from PRE; ‡=REP-2 and REP-3 different from PRE; †=REP-3 different ($p<0.05$) from PRE

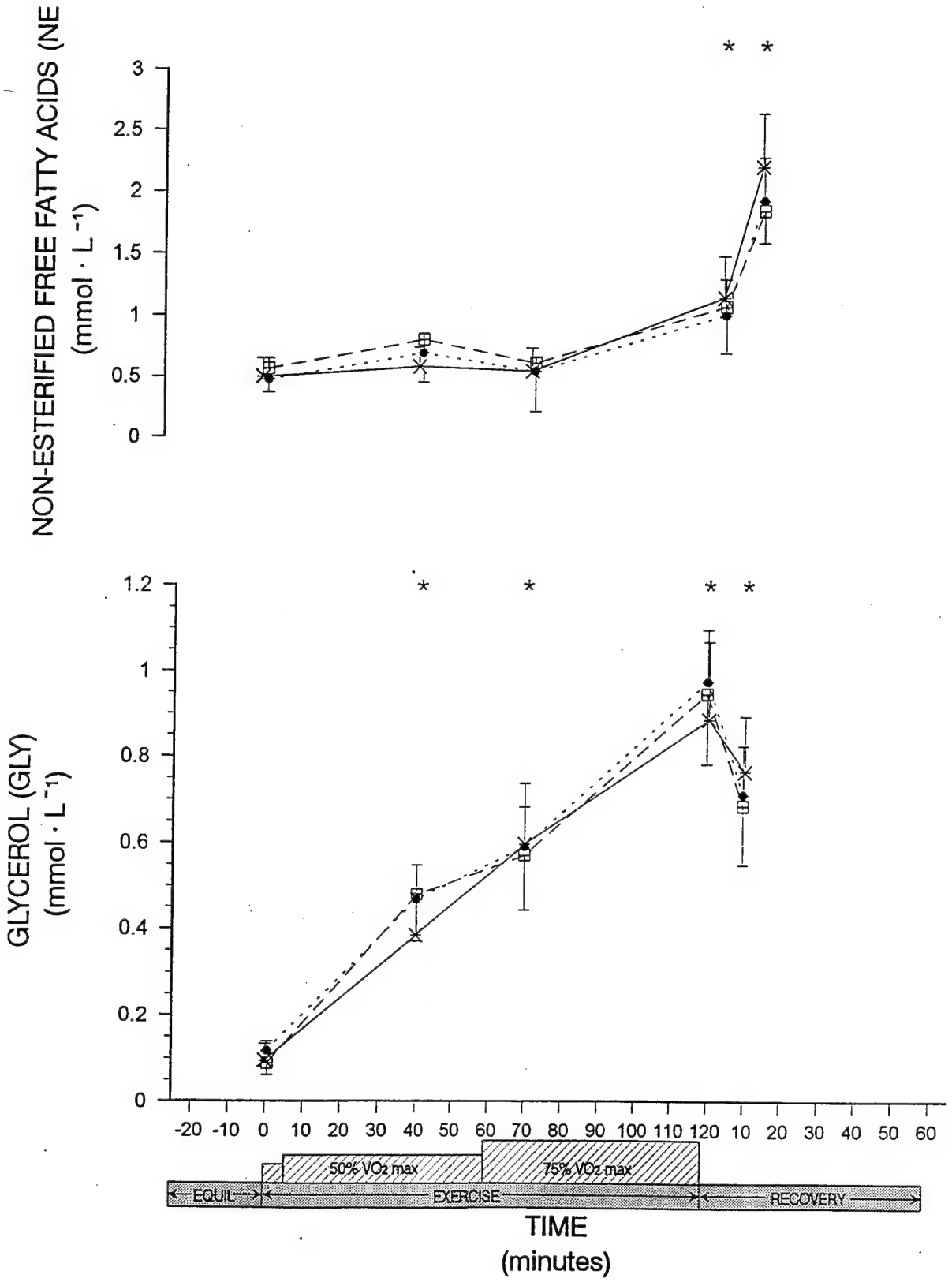

Figure 17. Non-esterified fatty acids (NEFA) and glycerol (GLY) ($\bar{X}\pm SD$) during REP trials; X—X=REP-1; ●- -●=REP-2, □---□=REP-3, *=all conditions different ($p<0.05$) from PRE.

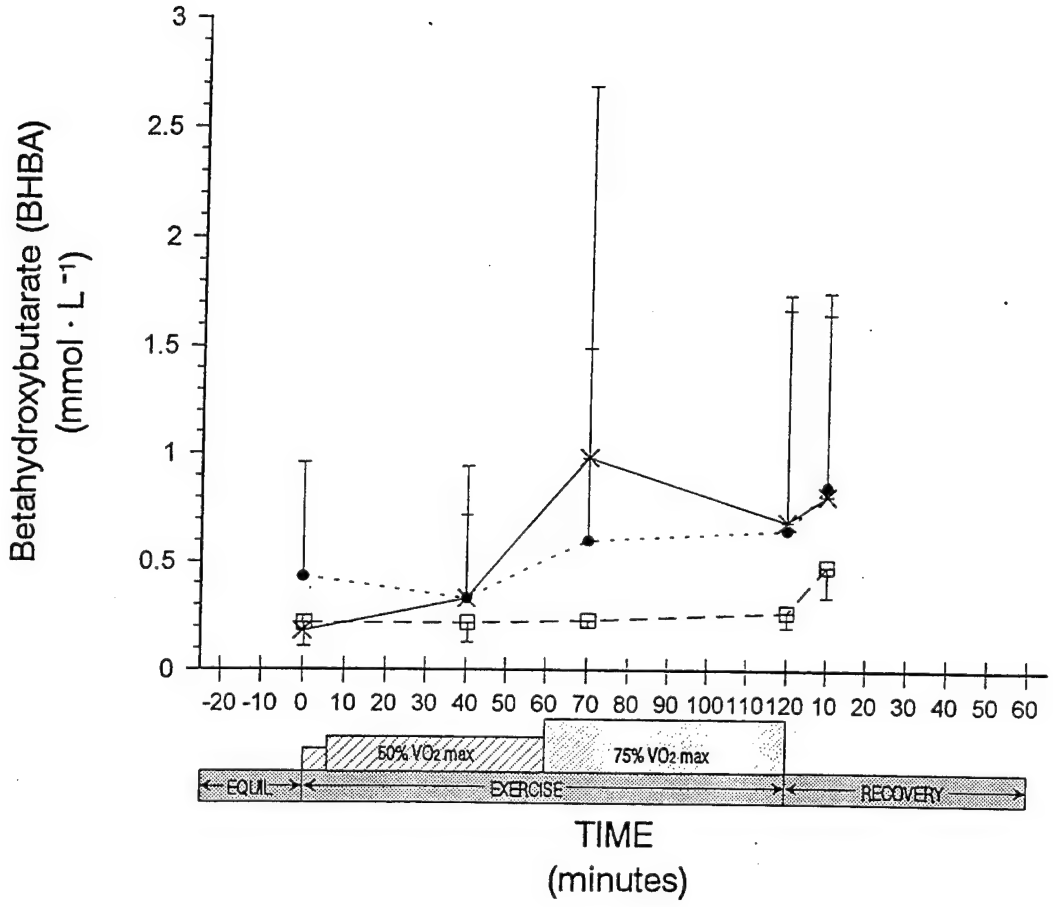

Figure 18. β-hydroxybutyrate (βHBA) ($\bar{X}\pm SD$) during REP trials; X—X=REP-1; ●- -●=REP-2, □---□=REP-3.

CONCLUSIONS

1. The central issue in this research investigation was the extent to which individual SOF soldiers differ in substrate utilization during prolonged physical exercise. Both the respiratory data and the biochemical parameters reflect a very consistent response from individual to individual and support the contention that despite differences in body weight, body composition, and physical training there is minimal variation in substrate utilization during exercise of the same relative intensity under the conditions of this study. Recommendations for optimal nutrition in the field, then, may be planned on basis of body weight, predicted total energy expenditure, predicted exercise intensity and duration, and environmental conditions without regard for individual metabolic differences.

2. Over the experimental period, both respiratory variables and some biochemical variables demonstrated a decrease in CV for the group of volunteers, indicating that metabolic variation between individual SOF soldier-volunteers decreased over the experimental period.

3. The high fat/low carbohydrate diet typically consumed by SOF soldiers in the field induces a transition to a fat predominant metabolism at rest and, in combination with a predominantly low-intensity exercise training program, induces an increase in the utilization of fat as an energy substrate.

4. An increasing number of volunteers were in slightly negative nitrogen balance from day 4 to day 9 of the experimental period. Although no strong conclusions may be made regarding nitrogen metabolism during this study, additional research on the interactive effects of diet and physical activity on protein metabolism during periods of intense physical activity are indicated.

5. SOF soldiers demonstrate a higher percentage fast twitch muscle fiber composition than the general population.

6. The somatotype of SOF soldiers is comparable in muscularity to Olympic athletes and to other Special Forces Operators (SEALs, BUD/S).

RECOMMENDATIONS

1. Since there is minimal metabolic variation between individual SOF soldiers, recommendations for optimal nutrition in the field may be made on basis of body weight, physical training status, predicted total energy expenditure for the mission, predicted exercise intensity and duration during the mission, and environmental conditions.

2. Muscle somatotype and fatiguability data indicate that the SOF soldier is more muscular and has a greater percent of fast twitch muscle fibers than males in the general population. This observation is consistent with previously reported data (Gabarée, 1994) and supports the contention that SOF soldiers are a distinct sub-group within the U.S. Army.

3. Additional research on the interactive effects of diet and physical activity on protein metabolism during periods of intense physical activity are indicated.

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APPENDICES

APPENDIX A
PHYSICAL CHARACTERISTICS
INDIVIDUAL DATA

	Age (years)	Height (cm)	Weight (kg)	Body Fat (%)	LBW (kg)	SA† (m^2)	M:SA‡
02	27	180.5	87.5	17.0	72.6	2.08	42.07
03	32	180.0	86.3	23.2	66.3	2.06	41.89
04	28	183.0	71.5	8.5	65.4	1.93	37.05
05	33	175.8	71.8	7.0	66.8	1.88	38.19
06	34	171.2	89.9	26.9	65.7	2.07	43.43
07	28	194.9	99.8	19.1	80.7	2.32	43.02
08	30	166.0	74.0	23.9	56.3	1.83	40.44
09	31	176.1	80.0	23.7	61.0	1.97	40.61
10	33	179.5	85.1	18.0	69.8	2.05	41.51
11	29	168.6	87.2	25.4	65.1	2.00	43.60
12	24	179.2	86.1	20.6	68.4	2.04	42.20
13	26	184.0	89.4	18.8	72.6	2.13	42.00
14	31	169.3	75.5	16.2	64.8	1.86	40.60
15	25	168.0	66.6	9.3	60.4	1.76	37.80
16	30	192.5	91.4	19.7	73.4	2.21	41.40
17	40	188.0	91.7	16.4	76.7	2.18	42.10
18	34	182.0	87.2	15.9	73.3	2.09	41.70
19	35	180.0	85.0	21.1	67.1	2.05	41.50

† DuBois surface area
‡ Mass-to-surface area ratio

APPENDIX B
SCHEMATIC OF THE RESEARCH DESIGN

Sub													
1 - 3	PRE	R	R	LAB	R	R	LAB	R	R	LAB	POST		
4 - 6		PRE	R	R	LAB	R	R	LAB	R	R	LAB	POST	
7 - 9			PRE	R	R	LAB	R	R	LAB	R	R	LAB	POST

10 -12	PRE	R	R	LAB	R	R	LAB	R	R	LAB	POST		
13 - 15		PRE	R	R	LAB	R	R	LAB	R	R	LAB	POST	
16 - 18			PRE	R	R	LAB	R	R	LAB	R	R	LAB	POST

Where: Sub= subject/volunteer number, PRE= day 1, R= rest day, LAB= experimental exercise protocol day, POST= day 11

APPENDIX C
SCHEDULE FOR EACH REST DAY (R-DAY)
DAYS 2, 3, 5, 6, 8, 9

0600-0800	awaken, urine collection, body weight, REE
0800-0830	breakfast
0830-0900	free time, light activity
0900-1030	exercise session
1030-1200	free time, light activity
1200-1300	lunch
1300-1400	free time, light activity
1400-1530	exercise session
1530-1800	free time, light activity
1800-1900	dinner
1900-2000	free time, light activity
2000-2300	light activity or sleep
2300	lights out

APPENDIX D
SCHEDULE FOR EACH EXPERIMENTAL EXERCISE DAY (E-DAY)
DAYS 4, 7, 10

0600-0615	awaken, urine collection, body weight
0615-0640	placement of catheter
0640-0700	equilibration period
0700-0900	exercise trial
0900-1000	post-exercise recovery period
1000-1100	breakfast
1100-1300	supervised rest period
1300--1315	snack
1315-1520	supervised rest period
1520-1540	report to laboratory, insertion of catheter
1540-1600	pre-exercise equilibration period
1600-1800	exercise trial
1800-1900	post-exercise recovery period
1900-2000	dinner
2000-2300	light activity or sleep
2300	lights out

APPENDIX E
THREE-DAY MENU

MENU 1: R DAY

AMOUNT	BREAKFAST	WEIGHT (g)
4 oz.	Orange Juice	118.0
1 oz.	Raisin Bran	28.4
2 pats	Margarine	10.0 g
2 ea.	Biscuits	122.8
2 ea.	Sausage Patties	77.1
8 oz.	Whole Milk	226.8
	LUNCH	
1 ea.	Ham and Cheese Sandwich:	
2 oz.	White Bread	50.0
2 oz.	Ham	56.7
1 oz.	American Cheese	28.4
	Lettuce Leaves	20.0
	Tomato Slices	28.4
1 pc	Mayonnaise	9.0
1 oz.	Doritos	28.4
2 ea.	Chocolate Chip Cookies	34.4
12 oz.	Diet Decaf. Soft Drink	369.6
	DINNER	
4 oz.	Beef Brisket	113.6
3 oz.	Mashed Potatoes	85.2
2 pats	Margarine	10.0
1 oz.	Beef Gravy	28.4
3 oz.	Broccoli Au Gratin	85.2
2 ea.	Croissants	113.6
4 pats	Margarine	20.0
1/2 cup	French Vanilla Ice Cream	72.6
12 oz.	Diet Decaf. Soft Drink	369.6
	SNACK	
6 ea.	Peanut Butter/Cheese Crackers	85.2
12 oz.	Diet Decaf. Soft Drink	369.6

MENU 2: R DAY

AMOUNT	BREAKFAST	WEIGHT (g)
8 oz.	Orange Juice	236.0
5 oz.	Scrambled Eggs	142.0
2 ea.	Sausage Patties	113.1
2 ea.	Biscuits	122.8
2 pats	Margarine	10.0
1 oz.	Grape Jelly	28.4
4 oz.	Whole Milk	113.4
	LUNCH	
3 oz.	Hamburger Patty	85.2
	Lettuce Leaves	20.0
	Tomato Slices	42.5
1 pc	Mayonnaise	9.0
1 ea.	Hamburger Bun	40.0
1 oz.	Doritos	28.4
2 oz.	Pound Cake	56.8
12 oz.	Diet Decaf. Soft Drink	369.6
	DINNER	
3 oz.	Chicken Breast	85.2
4 oz.	Rice Pilaf	113.6
1/2 cup	Green Beans	68.0
1 pat	Margarine	5.0
2 ea.	Dinner Rolls	61.2
2 pats	Margarine	10.0
2 ea.	Brownies	56.6
4 oz.	Whole Milk	113.4
	SNACK	
5 ea.	Ritz Crackers	
1 oz.	Cheddar Cheese	28.4
12 oz.	Diet Decaf. Soft Drink	369.6

MENU 3: E DAY

AMOUNT	BREAKFAST	WEIGHT (g)
4 oz.	Orange Juice	118.0
1 oz.	Corn Flakes	28.4
2.5 oz	Banana Slices	85.2
1 ea.	Biscuit	61.4
2 pats	Margarine	10.0
1 pc	Grape Jelly	14.2
8 oz.	Whole Milk	226.8
	SNACK	
1 ea.	Cheese Sandwich:	
2 oz.	American Cheese	56.8
1 pc	Mayonnaise	9.0
2 sl.	White Bread	50.0
1 oz.	Corn Chips	28.4
12 oz.	Diet Decaf. Soft Drink	369.6
	DINNER	
	Spaghetti with Meatballs	
6 oz.	Spaghetti	170.4
2 pats	Margarine	10.0
6 oz.	Spaghetti Sauce	170.4
6 oz.	Meatballs	170.4
1 oz.	Parmesan Cheese	28.4
	Tossed Salad	
2.5 oz.	Iceberg Lettuce	71.0
1 oz.	Diced Tomato	28.4
1 oz.	Cheddar Cheese	28.4
3 oz.	Avocado Slices	85.2
3 Tbsp	Bacon Bits	1.1
4 Tbsp	Ranch Salad Dressing	60.5

MENU 3: E DAY (cont.)

AMOUNT	DINNER	WEIGHT (g)
	Garlic Bread:	
1 sl.	Italian Bread	28.4
2 pats	Margarine	10.0
.25 tsp.	Garlic Powder	0.03
4 oz.	Whole Milk	113.4
1 cup	Vanilla Ice Cream	145.2
1/2 cup	Strawberries	128.8

APPENDIX F
PRE AND POST BODY WEIGHT AND PERCENT BODY FAT INDIVIDUAL DATA

#	PRE Weight (kg)	POST Weight (kg)	PRE Body Fat (%)	POST Body Fat (%)
02	87.5	86.8	17.0	-
03	86.3	85.8	23.2	-
04	71.5	71.2	8.5	9.0
05	71.8	71.9	7.0	7.1
06	89.9	88.9	26.9	27.5
07	99.8	99.0	19.1	17.5
08	74.0	74.0	23.9	23.3
09	80.0	79.7	23.7	23.1
10	85.1	84.6	18.0	-
11	87.2	87.2	25.4	23.5
12	86.1	85.7	22.9	20.3
13	89.4	90.2	21.1	-
14	75.5	75.5	16.3	-
15	66.6	66.0	9.3	8.5
16	91.4	90.5	16.1	-
17	91.7	-	19.7	15.5
18	87.2	86.4	15.9	17.5
19	85.0	85.5	21.1	20.4

APPENDIX G
ESTIMATED PERCENT FAST TWITCH MUSCLE FIBERS
INDIVIDUAL DATA

#	Fast Twitch (%)
02	65.5
03	66.1
04	55.7
05	50.9
06	52.4
07	-
08	58.9
09	50.7
10	63.1
11	78.5
12	48.9
13	40.4
14	58.5
15	63.6
16	66.4
17	64.7
18	75.1
19	75.9

APPENDIX H
INDIVIDUAL SOMATOTYPE DATA

#	Endomorphy	Mesomorphy	Ectomorphy
02	4.0	6.5	1.5
03	5.0	6.5	1.0
04	1.0	5.5	3.5
05	1.0	7.0	2.0
06	5.5	8.5	0.5
07	2.5	6.0	2.0
08	4.0	8.0	0.5
09	5.5	6.5	1.5
10	3.5	7.0	1.5
11	5.0	8.0	0.5
12	5.0	6.0	1.0
13	5.0	5.5	1.5
14	3.0	7.5	1.0
15	2.0	5.5	2.0
16	3.0	5.0	3.0
17	3.5	6.5	2.0
18	4.5	5.5	1.5
19	5.5	5.5	1.5

APPENDIX I
PRE AND POST
MAXIMAL HEART RATE (HR_{MAX}), MAXIMAL R-VALUE ($R\text{-}VALUE_{MAX}$), AND MAXIMAL OXYGEN CONSUMPTION ($\dot{V}O_2max$)
INDIVIDUAL DATA

	PRE HR_{MAX} (bpm)	POST HR_{MAX} (bpm)	PRE R-value$_{MAX}$ $\dot{V}CO_2/\dot{V}O_2$	POST R-value$_{MAX}$ $\dot{V}CO_2/\dot{V}O_2$	PRE $\dot{V}O_2max$ ($L \cdot min^{-1}$)	POST $\dot{V}O_2max$ ($L \cdot min^{-1}$)
02	189	185	1.24	1.07	4.65	4.58
03	187	178	1.09	1.16	4.70	4.37
04	185	179	1.11	1.04	4.47	4.00
05	182	172	1.20	1.05	4.14	4.10
06	197	186	1.18	1.16	4.00	4.30
07	198	189	1.10	1.07	5.02	5.00
08	181	175	1.20	1.09	3.50	3.70
09	181	176	1.17	1.01	3.63	3.50
10	184	176	1.11	1.01	4.44	3.50
11	198	185	1.14	0.99	4.44	4.32
12	187	180	1.06	1.05	4.95	4.92
13	190	-	1.09	-	4.82	-
14	188	183	1.12	1.08	3.77	3.76
15	195	184	1.17	0.97	4.22	3.65
16	187	173	1.19	1.05	4.17	4.34
17	184	-	1.21	-	4.50	-
18	188	177	1.17	1.14	4.22	3.98
19	208	191	1.11	1.04	4.13	4.40

APPENDIX J
DAILY INDIVIDUAL NITROGEN BALANCE

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
02	+8.01	+0.76	+0.71	+1.78	-1.58	-0.02	-1.15	+2.09	-3.95	+4.32
03	+4.95	-4.63	+4.60	-2.68	-2.21	-0.89	+0.36	-8.49	+2.19	+2.38
04	+6.17	-1.48	+1.68	-3.89	-2.11	-0.80	-4.01	-4.46	+0.10	-0.71
05	+5.45	-1.84	-3.05	+0.51	-1.35	+2.62	-7.74	-1.22	-10.41	-10.98
06	+6.57	+1.51	+1.17	+4.36	+4.04	-0.78	+5.67	-1.44	+4.61	+7.22
07	+4.45	+5.97	+4.35	+5.47	-3.91	+3.64	+1.15	-6.09	-0.68	+1.01
08	+5.65	+5.37	+8.00	+0.36	+6.28	-1.05	-0.45	+0.72	+1.42	-3.95
09	+6.06	-2.64	+3.66	+0.29	-0.99	+3.05	+1.74	-2.13	-1.12	+7.66
10	+4.01	-2.27	+1.12	+2.33	-0.58	-2.10	-1.82	+1.36	-5.30	+0.72
11	+6.42	+6.41	+7.63	-3.70	+3.33	+3.98	-1.85	+2.16	+3.10	-3.39
12	+12.25	+2.57	+6.88	+1.30	+4.10	+0.39	-0.64	-4.96	+1.89	+5.63
13	+13.30	+0.56	+13.20	+3.02	+6.49	+3.83	-6.67	+1.42	+6.23	-5.32
14	+6.17	-2.10	-1.03	-4.44	+4.08	-8.43	-7.32	-2.00	-3.47	+3.73
15	+6.03	+0.92	+2.97	-2.91	-2.64	-0.37	+0.25	+0.56	+2.90	-3.21
16	+10.17	+4.33	-5.14	+4.62	-2.46	-9.90	+4.43	-4.42	-11.53	-4.55
18	+8.90	-0.64	-0.72	-0.02	+0.11	+2.01	+4.34	-6.83	+1.26	-3.46
19	+2.40	+4.63	+13.49	-2.16	+0.97	+2.36	-12.08	+0.80	-1.25	-4.32
$\bar{X}$	6.88	1.03	3.50	0.25	0.68	-0.14	-1.52	-1.94	-0.82	-0.42
SD	±2.86	±3.38	±5.14	±3.14	±3.34	±3.92	±4.77	±3.38	±4.87	±5.11
CV	42%	328%	149%	1256%	491%	378%	325%	144%	405%	469%

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